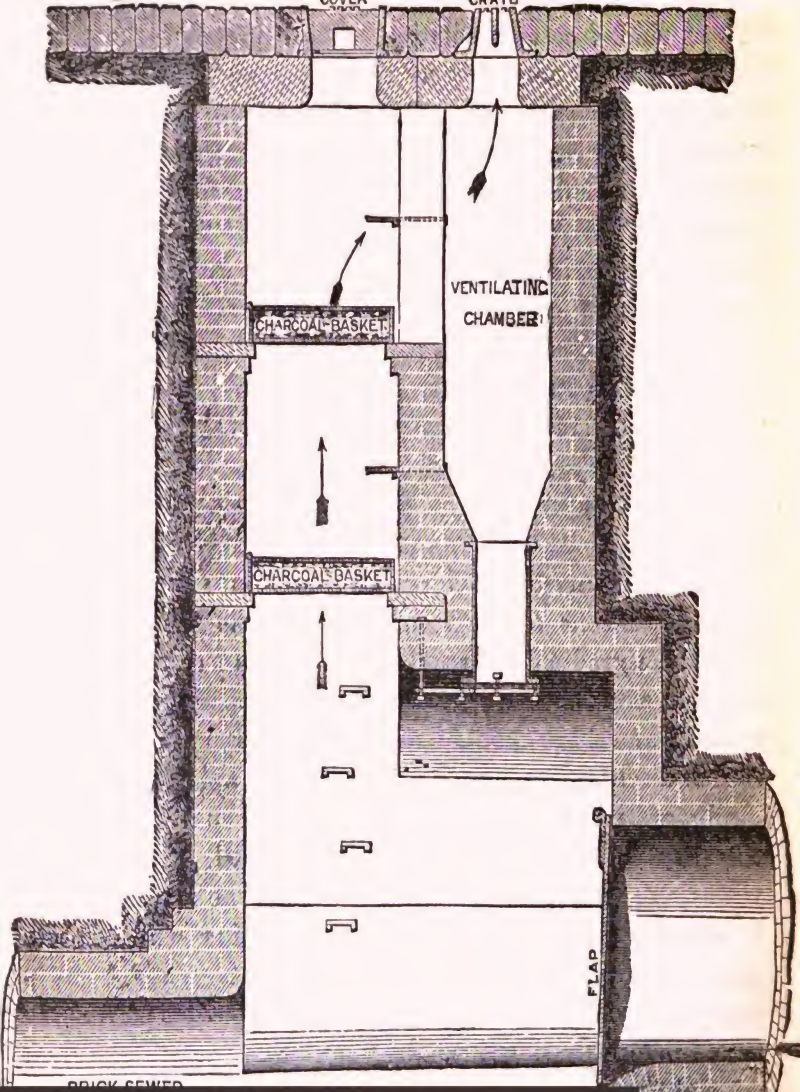

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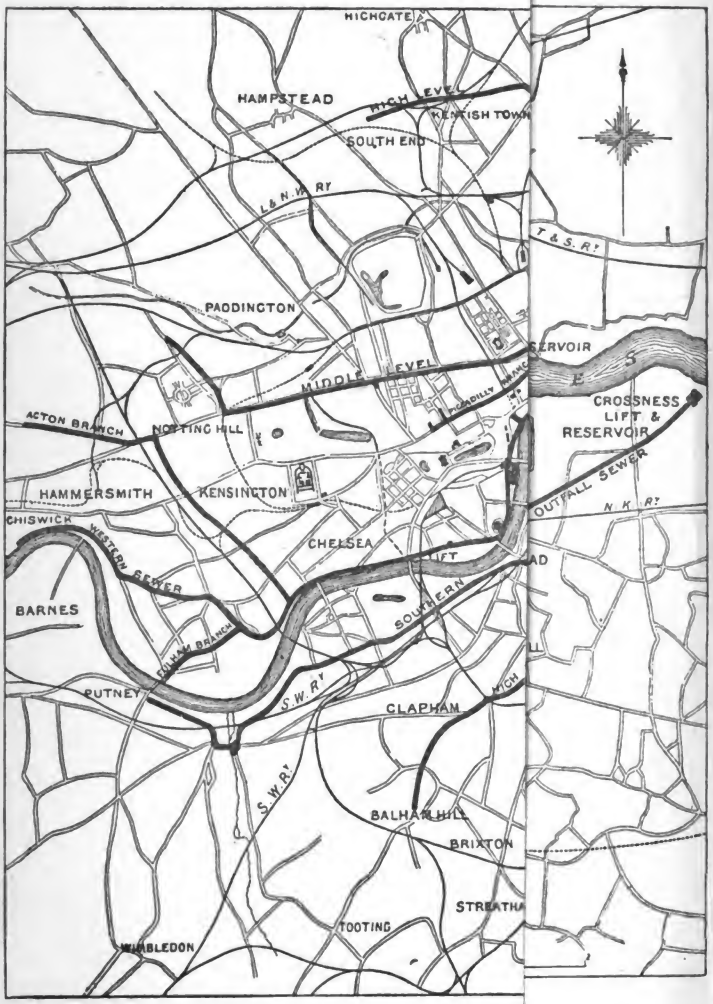

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ON THE

DRAINAGE

OF

LANDS, TOWNS, AND BUILDINGS

By G. D. DEMPSEY, C.E.

AUTHOR OF "THE PRACTICAL RAILWAY ENGINEER," ETC.

REVISED, WITH LARGE ADDITIONS

ON

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N. Y. W.

PREFACE.

THE excellent volumes on Drainage written by the late Mr. Dempsey having for some time been out of print, the publishers requested me to revise and to recast them in one volume, introducing new matter relating to recent practice in drainage. Much in those volumes which was necessarily speculative and transitory has been omitted, and some account of the grand works of the Metropolitan Main Drainage, and of interesting works of drainage engineering in other places, has been substituted. The sections of the original volumes treating of water supply have been entirely withdrawn, and room has thus been made for a notice of extensive land-drainage operations, and of the labour of skilled observers of rainfall, percolation, and evaporation in various countries.

Taken together, the new matter contributed by me amounts to just one-half of the volume. The principal source from which the substance of these recent contri-

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butions have been derived is that inexhaustible mine of engineering lore of the first rank—the "Minutes of Proceedings of the Institution of Civil Engineers," for the use of which I am indebted to the Council, who, with their usual liberality, have accorded unrestricted permission.

D. K. CLARK.

8, BUCKINGHAM STREET, ADELPHI, LONDON.
February, 1887.

NOTE TO THE SECOND EDITION.

The publishers are gratified to find that this work has met with so favourable a reception that a new edition is already required; and the opportunity has been taken to make some few corrections which had escaped attention when the work was passing through the press.

December, 1889.

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DRAINAGE

OF

LANDS, TOWNS, AND BUILDINGS.

INTRODUCTION.

DRAINAGE is the collecting and conveying away of refuse waters, and other matters, from lands, towns, and buildings. It ascertains the means and methods of accomplishing these purposes in the most complete manner; and, as water is the principal agent in all cleansing processes, the means required for insuring its supply are among the necessary provisions of efficient drainage. Sewers are among the essential means of town drainage, and therefore have to be so considered, and their positions, forms, sizes, and modes of construction duly ascertained. Our subject thus embraces several matters which may be treated separately, but which are properly branches of the art of draining, and cannot be consistently studied and usefully applied without a full appreciation of their several and intimate connections.

Water is indispensable to animal existence and health. The means of obtaining, treating, and economising this vital liquid are, therefore, among the most important objects of human art. The several sources, primary and secondary, of water, are the ocean, rivers, streams, lakes, subterranean collections or springs, and rain. Some or other of these sources are at our command, to some extent, at least, in every habitable region of the globe. The applicability

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of the first-named four sources is limited by the geographical position of the district; the latter two of them are obtainable nearly everywhere. The ceaseless cycle of operations by which the waters on the earth and of the ocean mingle with the atmosphere by the process of evaporation, and, descending in the forms of rain and dew, sprinkle the surface, and again unite through streams and rivers in their common reservoir, is one of the most beautiful and interesting illustrations of the compensating principle of the economy of Providence.

The proper serving of water for agricultural purposes, similarly with that for domestic and manufacturing uses, requires both adequate supply and discharge. That is, if the natural supply be deficient, it becomes the business of the drainer to augment it; if excessive, to reduce it. But, in either or any case, his correlative object is to provide sufficiently for the discharge of the water as rapidly as vegetation has imbibed its nutriment from it, and the supply is replenished. The recognition of this essential principle founded the era of all modern improvements in the Art of Draining. The most skilful tenders of the soil were previously satisfied to drain the surface of the land. So long as they were enabled by superficial channels to get rid of the excess of water which appeared above ground, their work seemed to them complete, and the effects of subterranean reservoirs and aluminous sponges, made visible in stunted and unhealthy vegetation, were attributed to any causes rather than the true ones.

Beyond the limits of the subject of draining as defined, it is also to be extended to the ultimate disposal of the refuse matters which it has first to remove from streets and dwellings: and one of its most important duties is to effect this disposal in such a manner that human health shall not be thereby impaired; and, moreover, that the matters removed shall be made available to the utmost in promoting the fertility of the land, and effecting all chemical purposes for which they are the best fitted.

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The history of the art, indeed, informs us that the Romans consulted the nature of the soil in selecting the form of their drains; that they provided for draining from springs and subterranean sources as well as from the surface; and that they were thoroughly conversant with the superiority of covered and deep drains in certain circumstances. Without attempting to pursue this history, however, which is abundantly interesting, but far beyond our space, we may recall to the minds of our readers the fact that, some century ago, the only method of draining generally practised in this country consisted of forming the surface into rude ridges and furrows, and cutting open trenches by the hedges to carry off some of the superabundant moisture. But, more than this, we are called upon to attest the fearful truth, that our own little island contains thousands upon thousands of acres of land in this same disgraceful condition, which have commonly been condemned as bad lands, and regarded as evidences of the misfortunes, instead of the ignorance, of their cultivators. The modern art appears to date principally from the methods instituted in the year 1764 by one Mr. Joseph Elkington, a Warwickshire farmer, who, happening to drive an auger through the bed of a trench, discovered the existence of a water-bearing stratum beneath, by drawing the water from which the surface and supersoil became thoroughly drained. The late Mr. Smith, of Deanston, and others, subsequently extended the principle of consulting the texture of the subsoils, and have adapted the depth, capacity, and construction of drains to these varieties of texture.

As early as the time of the Commonwealth, deep draining was advocated by Captain Walter Blith, who says—"Wherever you see drayning and trenching, you shall rarely finde few or none of them wrought to the bottome. But for these common and many trenches, ofttimes crooked too, that men usually make in their boggy grounds, some one foot, some two, I say away with them as a great piece

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of folly, lost labour and spoyle. And for thy drayning trench it must be made so deepe that it go to the bottome of the cold spewing moyst water that feeds the flagg and rush—a yard or 4 feet deepe if ever thou wilt drain to any purpose." And "to the bottome where the spewing spring lyeth thou must go, and one spade's graft beneath, how deepe soever it be, if thou wilt drain thy land to purpose."

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DIVISION I.

DRAINAGE OF LANDS.

SECTION I.

Sources of Water.—Rainfall.—Evaporation.—Percolation.—Nature of Soils and Crops.

In adopting the terms natural and artificial supply as contradistinguished, it may appear that the former should apply commonly to all the sources enumerated, except the subterranean. We would, however, limit the term natural supply to rain and dew, since all the other sources require more or less of artificial means before they are generally available for the purposes of man. Thus the water of the ocean must undergo chemical change or distillation, and that of rivers requires artificial channels and conduits for its distribution. These, therefore, like the subterranean, for which wells and borings are necessary, have to be classed among the artificial sources of water.

The quantity of evaporation from land-surface is evidently more limited than that from water-surface, the one depending upon the retentive power of the super-soil, and the facility for capillary action, while the other arises from a source comparatively inexhaustible. The rate of the process is controlled by temperature, and accelerated in proportion to the heat acting upon the surface; the temperature being effected by the elevation, and reduced in proportion as the elevation increases. The joint result of these conditions is, that proximity to the sea, the river, or the lake, promotes the natural supply of water in the form

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of rain. The geography of the district, therefore, affects the facility or difficulty of the natural supply.

But another consideration also affects this supply, viz., the superficial features of the district. Thus a mountainous character, augmenting the surface exposed to oblique showers, increases the quantity received on the one side, and diminishes that on the other; and the sides of a valley, in like manner, receive more or less than the quantity due to a level district.

The natural supply is, moreover, modified in effect by the structure of the surface on which it falls. Thus, upon a rock-surface (such as that presented by mountains), which resists percolation, the rain collects in masses, floods itself through a fissure, or wears a channel along the line of the most pervious formation, and reaches the lower plains in the formidable rush of a mountain torrent. And as, generally, the effect of the natural supply of water is in proportion to the comparative impermeability of the soil, it follows that the value of this supply in any district is further conditional on the structural character of the adjacent districts. Thus, from a higher impermeable district it will receive, and to a lower more permeable district it will give. Natural supply is hence, in effect, determined by the geographical situation, the superficial character, and the geological structure of a district, modified also by the structure of the surrounding district.

The quantity of rain that falls annually at several places, has been observed and recorded as follows:—

In England, the mean annual depth for the eight years 1836 to 1843, both included, was 26·61 inches, having varied between the extremes of 21·1 and 32·1 inches. The average annual fall at some other places has been recorded as follows:—

	Inches.
South Carolina	50
Bombay (mean of 10 years)	78
Brazil (in 1821)	280
Cumana	8

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Humboldt has assigned the fall of rain to vary with the latitude, being greatest at the equator, and diminishing towards the poles in the following ratio: viz., 96 inches annually in the equatorial zone, 80 inches to latitude 20°, 29 inches to latitude 45°, and 17 inches to latitude 60°.

The quantity of rain thus varying, with some reference to the latitude, also to the position of the district in relation to the sea, and varying also from one year to another, is further affected by the season. Thus, the mean fall per month on an average of eight years in some districts of England has been recorded as fluctuating from 1·617 inch in March to 3·837 inches in November; the fall in each month being as follows:—

TABLE I.—RAINFALL—AVERAGES OF EIGHT YEARS.

	Inches.
January	1·847
February	1·971
March	1·617
April	1·456
May	1·856
June	2·213
July	2·287
August	2·427
September	2·639
October	2·823
November	3·837
December	1·641
	26·614

This monthly quantity, being the mean of eight years, does not by any means indicate the monthly proportion for any one year, the variation being as great between the same months of different years, as it is from one year to another, or indeed from one latitude to another. Thus, during the eight years over which these observations extended, the quantity of rain falling in each month was as follows:—

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TABLE II.—Rainfall for Eight Years.

Month.	Years.							
	1836.	1837.	1838.	1839.	1840.	1841.	1842.	1843.
	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.
January	2·40	2·40	0·31	1·40	3·95	1·50	1·36	1·46
February.....	2·04	2·85	2·65	1·45	1·32	1·02	2·02	2·42
March	3·65	0·75	1·55	1·92	0·34	1·65	2·20	0·88
April	2·57	1·32	1·35	1·65	0·34	1·85	0·47	2·10
May	0·70	0·94	0·84	1·22	2·62	1·68	1·85	5·00
June.....	1·80	1·86	2·85	3·31	1·33	3·00	2·00	1·56
July	2·29	1·30	2·35	4·36	1·68	2·80	1·93	2·09
August.....	2·24	3·00	0·95	3·65	1·90	3·62	1·40	2·66
September	2·60	1·38	2·47	3·22	2·31	4·00	4·50	0·63
October	4·55	1·55	2·68	1·68	1·50	4·40	1·41	4·82
November	3·95	2·05	3·55	4·40	4·25	4·28	5·77	2·45
December	2·21	1·70	1·58	3·62	0·40	2·30	1·52	0·40
Quantity in each year ..	31·00	21·10	23·13	31·28	21·44	32·10	26·43	26·47

We may quote a few words from the celebrated Dalton, which will be fully suggestive to the studious mind in this interesting department of meteorological science. "The cause of rain is now, I consider, no longer an object of doubt. If two masses of air of unequal temperatures, by the ordinary currents of the winds, are intermixed, when saturated with vapour, a precipitation ensues. If the masses are under saturation, then less precipitation takes place, or none at all, according to the degree. Also, the warmer the air, the greater is the quantity of vapour precipitated in like circumstances." "Hence the reason why rains are heavier in summer than in winter, and in warm countries than in cold." *

The depth of rain which falls is ascertained by receiving it in a vessel of some form with a gauge connected, in which the depth may be accurately measured. The rain-

* Memoirs of the Literary and Philosophical Society of Manchester; vol. iii., second series, 1819, p. 507. Several valuable papers, with detailed observations made during long series of years, by Dr. Dalton and others, are to be found in these Memoirs.

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gauge used by Dr. Dalton for a series of experiments extending from 1795 to 1819, or later, consisted of "a funnel of 10 inches diameter, and the top surrounded by a perpendicular rim of 3 inches high, to prevent any loss by the spray; it was fixed in a proper frame with a bottle for the water, and stood above 2 feet above ground."

The effectiveness of rain for all purposes of water-supply and drainage can be estimated only after determining the deduction due to the process of evaporation, by which the larger part of it is raised from the surface on which it has fallen, and, in the form of vapour, mingles with the atmosphere, to be again precipitated upon the earth and ocean. The proportion evaporated appears to be mainly dependent upon the temperature, heat promoting the process, and cold retarding it. The highest, lowest, and mean temperature in each month have been observed to be as follows:—

TABLE III.—TEMPERATURES.

MONTH.	THERMOMETER.		
	Highest.	Lowest.	Mean.
January	52°·0	11°·0	36°·1
February	53 ·0	21 ·0	38 ·0
March	66 ·0	24 ·0	43 ·9
April	74 ·0	29 ·0	49 ·9
May	70 ·0	33 ·0	54 ·0
June	90 ·0	37 ·0	58 ·7
July	76 ·0	42 ·0	61 ·0
August	82 ·0	41 ·0	61 ·6
September	76 ·0	36 ·0	57 ·8
October	68 ·0	27 ·0	48 ·9
November	62 ·0	23 ·0	42 ·9
December	55 ·0	17 ·0	39 ·3

And, accordingly, we find the proportion of rain evaporated corresponds with the temperature recorded thus:— being the mean evaporation of each month during the

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eight years 1836 to 1843, and stated at per cent. upon the quantity of rain.

TABLE IV.—Rainfall—Percentage of Evaporation.

Month.	Evaporation per cent.	Remainder per cent.
January	29·3	70·7
February	21·6	78·4
March	33·4	66·6
April	79·0	21·0
May	94·2	5·8
June	98·3	1·7
July	98·2	1·8
August	98·6	1·4
September	86·1	13·9
October	50·5	49·5
November	15·1	84·9
December	00.0	100·0
Mean	57·6	42·4

The remainder stated in the last column shows the percentage upon the total quantity falling which is available for human purposes.

Besides the main condition of temperature, other minor circumstances affect the proportion of rain which passes from the surface in the state of vapour, and have to be considered in forming an estimate, from these records, of the available quantity of rain-water in any district. These minor conditions are chiefly the structure and the state of the supersoil and of the subsoil. Thus, if the structure be of an impermeable character, the water will lie upon the surface, while evaporation takes up more than its average quantity, being hindered only by the provision which may exist for passing the rain immediately to a more porous surface. On the other hand, a soil of excessive permeability will imbibe the water rapidly, and thus reduce the amount of evaporation. The state of the soil affected by the frequency and extent of the showers will, moreover, determine in some degree the relative quantities

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of rain-water evaporated and retained. Thus, if the soil has acquired excessive hardness from long drought, or become super-saturated by excessive rain, evaporation will proceed more rapidly than percolation, and the effect of the fall be similarly diminished.

The average quantity remaining to filter through the soil, or to be made use of for the purposes of man, may be computed from the following Table, No. V., which shows the average monthly fall during the same period of eight years as stated in Table No. I., the quantity evaporated, and the quantity remaining, in inches.

TABLE V.—RAINFALL AND EVAPORATION—AVERAGES FOR EIGHT YEARS.

MONTH.	RAIN.		
	Total falling.	Evaporated.	Remaining.
	Inches.	Inches.	Inches.
January	1·847	0·540	1·307
February	1·971	0·424	1·547
March	1·617	0·540	1·077
April	1·456	1·150	0·306
May	1·856	1·748	0·108
June	2·213	2·174	0·039
July	2·287	2·245	0·024
August	2·427	2·391	0·036
September	2·639	2·270	0·369
October	2·823	1·423	1·400
November	3·837	0·579	3·258
December	1·641	0·164	1·805
	26·614	15·320	11·294

The following observations, Table No. VI., on evaporation and filtration,* for which we are indebted to the patient and carefully conducted experiments of Mr. Charles Char-

* Quoted by J. H. Charnock, Esq., Assistant Commissioner under the Drainage Acts, in a paper "On Suiting the Depth of Drainage to the Circumstances of the Soil," given in the Journal of the Royal Agricultural Society, vol. x. pt. ii. pp. 515 to 518.

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TABLE VI.—An Account of Observations made, through a series of Five Years, at Holmfield House, near Ferrybridge, in the County of York, by Charles Charnock, Esq., with a view to determine the amount of Evaporation and Filtration under the several circumstances on the Magnesian Limestone Soil.

Explanation.—Column 1.—Shows the Depth of Rain fallen, as registered by the ordinary Rain-Gauge.

Column 2.—Is the Amount of evaporation from a Surface of Water fully exposed to both Sun and Wind.

Column 3.—Is the Evaporation from Water, shaded from the Sun, but exposed to the Wind.

Column 4.—Is the Evaporation from what represented drained or dried land.

Column 5.—Is the Evaporation from the same when saturated.

Column 6.—Is the amount of water which filtered through the soil.

Into a leaden vessel, of a foot square and three feet deep, was put two feet of gravel and calcareous sand, so as to represent the substratum of the farm, and the remainder filled up, to within an inch of the top, with an average quality of soil. At the bottom a pipe was inserted, which conveyed all the water which was filtered through into a bottle, which was regularly emptied and registered. The vessel was inserted in the ground to within an inch of the surface, keeping the level of the soil, inside and outside, alike, with an inch of the vessel above, to prevent any communication of water from without. The soil was kept free from weeds, and occasionally stirred, that it might not be more than ordinarily compact.

Months.	1842.						1843.					
	Rain.	Evaporation.				Filtration.	Rain.	Evaporation.				Filtration.
	1	2	3	4	5	6	1	2	3	4	5	6
	On the Surface.	From Water. Exposed to both Sun and Wind.	From Water. Shaded from Sun, but exposed to Wind.	From Soil. When drained.	From Soil. When saturated.	Through the Soil from the Drain 3 ft. deep.	On the Surface.	From Water. Exposed to both Sun and Wind.	From Water. Shaded from Sun, but exposed to Wind.	From Soil. When Drained.	From Soil. When Saturated.	Through the Soil from the Drain 3 ft. deep.
January	2·70	1·69	1·13	1·66	1·59	1·04	1·48	2·57	1·71	0·69	1·87	0·79
February	0·76	1·23	0·81	0·68	1·04	0·08	3·25	2·65	1·10	2·29	2·78	0·96
March	3·48	1·92	1·28	2·40	2·52	1·08	0·95	3·05	2·03	0·72	2·43	0·23
April	1·51	2·98	1·99	1·11	2·31	0·40	2·19	3·22	2·05	1·84	2·39	0·25
May	2·98	4·14	2·76	2·89	3·82	0·09	2·81	2·91	1·94	2·47	2·65	0·34
June	1·94	4·18	2·79	1·94	4·27	—	2·31	5·12	3·41	2·10	4·86	0·21
July	3·74	4·16	2·73	3·20	3·89	0·48	2 70	3·76	2·50	2·55	3·49	0·15
August	1·49	3·36	2·24	1·37	2·39	0·12	3·99	3·71	2·57	3·77	6·74	0·22
September	2·44	2·39	1·74	2·24	2·88	0·20	1·07	2·06	1·34	0·90	2·18	0·17
October	1·12	2·00	1·37	0·92	1·99	0·20	1·10	1·80	1·20	0·82	1·93	0·28
November	3·19	2·26	1·50	2·49	1·83	0·70	2·30	1·64	1·09	1·69	1·48	0 67
December	0·76	3·00	2·14	0·60	1·49	0·16	0·28	1·68	1·78	0·27	1·39	0·01
Totals	26·11	33·61	22·48	21·56	30·02	4·55	24·49	34·17	22·72	20·11	31·19	4·28

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TABLE VI.—*continued.*

Months.	1844.							1845.							1846.						
	Rain.	Evaporation.					Filtration.	Rain.	Evaporation.					Filtration.	Rain.	Evaporation.					Filtration.
	1	From Water.		From Soil.			6	1	From Water.		From Soil.			6	1	From Water.		From Soil.			6
	On the Surface.	Exposed to both Sun and Wind.	Shaded from Sun, but exposed to Wind.	When Drained.	When Saturated.	Through the Soil from the Drain 3 ft. deep.		On the Surface.	Exposed to both Sun and Wind.	Shaded from Sun, but exposed to Wind.	When drained.	When Saturated.	Through the Soil from the Drain 3 ft. deep.		On the Surface.	Exposed to both Sun and Wind.	Shaded from Sun, but exposed to Wind.	When Drained.	When Saturated.	Through the Soil from the Drain 3 ft. deep.
January	1·31	1·61	1·08	0·85	1·50	0·46		1·74	1·53	1·02	1·28	1·49	0·46		2·18	2·07	1·58	1·22	1·94	0·06	
February	2·22	1·31	0·88	1·66	1·71	0·56		0·73	0·71	0·47	0·43	0·04	0·30		0·17	2·59	1·60	0·44	2·09	0·03	
March	2·27	2·13	1·42	1·58	1·50	0·69		1·88	2·91	1·94	1·33	2·89	0·55		0·03	2·56	1·55	0·86	2·16	0·07	
April	0·27	3·83	2·55	0·27	3·42	—		1·54	4·79	3·19	1·05	4·06	0·39		5·07	1·01	1·22	2·08	1·49	2·99	
May	0·42	5·77	3·85	0·42	4·86	—		2·24	2·84	1·99	1·97	3·26	0·27		0·82	4·52	3·02	0·71	3·89	0·09	
June	1·24	5·31	3·58	1·20	4·95	0·04		3·18	3·10	2·06	2·93	2·98	0·25		1·05	4·88	3·25	1·58	4·73	0·07	
July	2·76	4·17	2·78	2·43	4·28	0·33		3·49	2·86	1·89	8·30	2·79	0·19		2·90	4·44	2·96	2·74	4·39	0·16	
August	2·85	4·70	3·14	2·44	4·63	0·41		4·61	2·56	1·70	4·24	2·43	0·37		2·05	3·08	2·05	2·46	3·28	0·19	
September	1·92	4·91	3·28	1·62	3·96	0·30		1·36	2·79	1·86	0·95	2·29	0·41		1·07	2·99	1·99	1·00	3·14	0·07	
October	1·41	2·79	1·86	1·17	2·93	0·24		3·36	2·77	1·84	2·69	2·82	0·67		4·00	2·20	1·49	2·40	2·76	1·69	
November	1·98	2·84	1·80	1·47	2·78	0·51		1·01	2·13	1·41	0·73	2·20	0·28		1·15	1·63	1·09	0·88	1·74	0·17	
December	0·35	0·79	0·53	0·29	0·93	0·06		3·04	3·57	2·38	2·30	2·87	0·68		1·36	1·79	1·10	1·09	1·67	0·27	
Totals	19·00	40·16	26·75	15·40	37·85	3·60		28·18	32·56	21·75	23·26	31·00	4·92		25·24	34·69	23·04	18·38	33·28	6·76	

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nock, of Holmfield House, near Ferrybridge, present some valuable facts for consideration.

In these experiments, the evaporation from saturated soil was determined thus :—"A leaden vessel of 13 inches deep, and a foot square, was filled to within an inch of the top with soil, and placed in the ground in the same manner as the previous vessel, with a pipe level with the surface of the soil to carry off the excess of top-water into a receiver. The same quantity of water was then daily supplied to this soil as the evaporating dish of column 2 showed was evaporated. The soil was stirred as in the former case, and thus represented wet and undrained land.

"In the first place, it is observable how much greater is the amount of evaporation from water than from land, and how near, as shown by columns 2 and 5 (Table VI. pp. 12, 13), the evaporation from wet land is to that from water itself;—hence the wetter the land the greater the evaporation, and, as the well-known consequence, the greater its excess of coldness. We have a familiar illustration of nature's process in this particular, in the method often adopted to cool our wine on a hot summer's day, by wrapping a wet napkin round the bottle and exposing it to the full sun: as the moisture from the napkin is evaporated, the temperature of the wine declines to almost freezing point. The schoolboy's experiment of producing ice before a fire, by incasing the vessel in wet flannel and adding a portion of salt to the water, is a similar example, with this additional lesson to the farmer—that to apply certain limes to wet land is only increasing the evil.

"You will then, in the second place, notice how much less the evaporation is in the shade than in the sun, and consequently that wet land must be the warmest when there is the least sun. From which cause, no doubt, arises that too vigorous growth of young wheat, so often observable on such land in the winter and spring months, which never fails to produce serious injury to the crop in all its subsequent stages. And thirdly, you will remark how

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comparatively small a proportion of the rain which falls is shown to be carried off by filtration."

The precise quantity of water required for the agricultural purposes of any district depends upon the nature of the soil and the crops, and the position of the district in relation to the surrounding country. Thus, if a permeable soil occupy an elevated site, the water deposited upon it will pass rapidly, and perhaps before serving for the germination or the nutriment of the plant. If, on the other hand, as is the far more common case in this country, the soil be of a retentive character, and the site low in relation to other districts, the water will be kept, while the soil becomes saturated to so great an extent that the processes of vegetable germination and growth are greatly impeded. The soil exists in one of three conditions: 1st, in the form of clay, being a dense mass consisting of finely comminuted particles, but all of a highly tenacious kind; in a state of slight moisture it becomes a clammy paste, and is never found so utterly devoid of moisture that its constituent particles are separable: it affords no passages for water, receiving it with difficulty, and retaining it in the same way. 2nd, in the form of sand or gravel, the particles of which are seldom or never united, and the soil is therefore full of passages or canals for water. Soil of this kind has no power either to oppose the admission or effect the retention of water poured upon it. And 3rd, existing in the form of a mixture of the aluminous, silicious, and calcareous elements, in endless variety of proportions, found as clods, and in this state affording two classes of passages for the ingress and permeation of water, viz., those remaining between the particles which are congelated in each clod, and those formed by the spaces between the clods. The former are sometimes called pores, and the latter canals. The power of admitting and retaining or discharging water exerted by these mixed soils, will exist in an endless variety of degrees, according to the mechanical formation of the constituent particles and clods. The state of soil which is

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most favourable for the germination and development of the plant is that of moistness, capable of being readily crumbled by the hand, and equally removed from the adhesive extreme of mud and the volatile one of dust. In this condition it will be found that the pores are filled with water, but the *canals* are not—these latter serving as passages for the air, which is one of the feeders of vegetable life; and we can therefore readily understand that when water exists in such quantity that the soil is saturated with it, and all the pores or canals filled, its condition is unhealthy for the growth and development of plants.

The following extract, from an admirable lecture on Agricultural Science, by Dr. Madden, quoted by the General Board of Health in their "Minutes of Information," although of considerable length, claims a space here, for the valuable information it conveys on the fitness of soil for promoting vegetable germination.

"The first thing which occurs after the sowing of the seed is, of course, germination; and before we examine how this process may be influenced by the condition of the soil, we must necessarily obtain some correct idea of the process itself. The most careful examination has proved that the process of germination consists essentially of various chemical changes, which require for their development the presence of air, moisture, and a certain degree of warmth. Now it is obviously unnecessary for our present purpose that we should have the least idea of the nature of these processes: all we require to do, is to ascertain the conditions under which they take place; having detected these, we know at once what is required to make a seed grow. These, we have seen, are air, moisture, and a certain degree of warmth; and it consequently results that wherever a seed is placed in these circumstances, germination will take place. Viewing matters in this light, it appears that soil does not act chemically in the process of germination; that its sole action is confined to its being the vehicle by means of which a supply of air and moisture

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and warmth can be continually kept up. With this simple statement in view, we are quite prepared to consider the various conditions of soil, for the purpose of determining how far these will influence the future prospects of the crop, and we shall accordingly at once proceed to examine carefully into the mechanical relations of soil.

"Soil, examined mechanically, is found to consist entirely of particles of all shapes and sizes, from stones and pebbles down to the finest powder; and on account of their extreme irregularity of shape, they cannot lie so close to one another as to prevent there being passages between them, owing to which circumstance soil in the mass is always more or less porous. If, however, we proceed to examine one of the smallest particles of which soil is made up, we shall find that even this is not always solid, but is much more frequently porous, like soil in the mass. A considerable proportion of this finely divided part of soil, the impalpable matter, as it is generally called, is found, by the aid of the microscope, to consist of broken-down vegetable tissue, so that when a small portion of the finest dust from a garden or field is placed under the microscope, we have exhibited to us particles of every variety of shape and structure, of which a certain part is evidently of vegetable origin.

"On examining a perfectly dry soil we perceive that there are two distinct classes of pores: 1st, the large ones, which exist between the particles of soil; and 2nd, the very minute ones, which occur in the particles themselves; and whereas all the larger pores—those between the particles of soil—communicate most freely with each other, so that they form canals, the small pores, however freely they may communicate with one another in the interior of the particle in which they occur, have no direct connection with the pores of the surrounding particles. Let us now, therefore, trace the effect of this arrangement. If the soil is perfectly dry, the canals communicating freely at the surface with the surrounding atmosphere, the whole of these canals and

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pores will, of course, be filled with air. If, in this condition, a seed be placed in the soil, you at once perceive that it is freely supplied with air, but there is no moisture; therefore, when soil is perfectly dry a seed cannot grow.

"Let us turn our attention now to that state of the soil in which water has taken the place of air, or, in other words, the soil is very wet. If we observe our seed now, we find it abundantly supplied with water, but no air. Here again, therefore, germination cannot take place. It may be well to state here that this can never occur exactly in nature, because water having the power of dissolving air to a certain extent, the seed is in fact supplied with a certain amount of this necessary substance, and owing to this germination does take place, although by no means under such advantageous circumstances as it would were the soil in a better condition.

"We pass on now to a different state of matters. Let us suppose the canals are open and freely supplied with air, while the pores are filled with water. While the seed now has quite enough of air from the canals, it can never be without moisture, as every particle of soil which touches it is well supplied with this necessary ingredient. This, then, is the proper condition of soil for germination, and, in fact, for every period of the plant's development; and this condition occurs when soil is moist but not wet—that is to say, when it has the colour and appearance of being well watered, but when it is still capable of being crumbled to pieces by the hands, without any of its particles adhering together in the familiar form of mud.

"Let us observe still another condition of soil; in this instance, as far as water is concerned, the soil is in its healthy condition—it is moist but not wet, the pores alone being filled with water. But where are the canals? We see them in a few places, but in by far the greater part of the soil none are to be perceived; this is owing to the particles of soil having adhered together, and thus so far obliterated the interstitial canals that they appear only like

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pores. This is the state of matters in every clod of earth; and you will at once perceive, on comparing it with a stone, that it differs from it only in possessing a few pores, which latter, while they may form a reservoir for moisture, can never act as vehicles for the food of plants, as the roots are not capable of extending their fibres into the interior of a clod, but are at all times confined to the interstitial canals.

"With these four conditions before us, let us endeavour to apply them practically to ascertain when they occur in our fields, and how those which are injurious may be obviated.

"The first of them, we perceive, is a state of too great dryness, a very rare condition, in this climate at least; in fact, the only case in which it is likely to occur is in very coarse sands, where the soil, being chiefly made up of pure sand and particles of flinty matter, contains comparatively much fewer pores, and, from the large size of the individual particles, assisted by their irregularity, the canals are wider, the circulation of air freer, and, consequently, the whole is much more easily dried. When this state of matters exists, the best treatment is to leave all the stones which occur on the surface of the field, as they cast shades, and thereby prevent or retard the evaporation of water.

"We will not, however, make any further observations on this very rare case, but will rather proceed to a much more frequent, and, in every respect, more important condition of soil, an excess of water.

"When water is added to perfectly dry soil, it of course, in the first instance, fills the interstitial canals, and from these enters the pores of each particle; and if the supply of water be not too great, the canals speedily become empty, so that the whole of the fluid is taken up by the pores: this, we have already seen, is the healthy condition of soil. If, however, the supply of water be too great, as is the case when a spring gains admission into the soil, or when the sinking of the fluid through the canals to a sufficient depth below the surface is prevented, it is clear that

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these also must get filled with water so soon as the pores have become saturated. This, then, is the condition of undrained soil.

"Not only are the pores filled, but the interstitial canals are likewise full, and the consequence is that the whole process of the germination and growth of vegetables is materially interfered with. We shall here, therefore, briefly state the injurious effects of an excess of water, for the purpose of impressing more strongly on your minds the necessity of thorough draining, as the first and most essential step towards the improvement of your soil.

"The first great effect of an excess of water is, that it produces a corresponding diminution of the amount of air beneath the surface, which air is of the greatest possible consequence in the nutrition of plants; in fact, if entirely excluded, germination could not take place, and the seed sown would, of course, either decay or lie dormant.

"Secondly, an excess of water is most hurtful, by reducing considerably the temperature of the soil: this I find by careful experiment to be to the extent of 6½ degrees Fahrenheit in summer, which amount is equivalent to an elevation above the level of the sea of 1,950 feet. So that, supposing two fields lying side by side, the one drained, the other undrained, and supposing them both equally well cultivated, there will be nearly as much difference in the amount and value of their respective crops, as if the drained one was situated at the level of the sea, and the other had an elevation as high as the most lofty of the Pentland Hills.* But besides this, and what is nearly equally bad, the temperature is rendered unnaturally high during winter; whereas it has been proved that one great source of health and vigour in vegetation is the great difference which exists between the temperature of summer and winter, which difference amounts in dry soil to between

* Of course the field of high elevation must be thoroughly drained to equal even the undrained field at the level of the sea.

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thirty and forty degrees, while in soil very much injured by an excess of water, the whole range of the thermometer throughout the year will probably not exceed from six to ten degrees.

"These are the two chief injuries of an excess of water in soil which affect the soil itself. There are very many others affecting the climate, &c.; but these are not so connected with the subject in hand as to call for an explanation here.

"Of course all these injurious effects are at once overcome by thorough draining, the result of which is to establish a direct communication between the interstitial canals and the drains, by which means it follows that no water can remain any length of time in these canals without, by its gravitation, finding its way into the drains.

"Too much cannot be said in favour of pulverising the soil; even thorough-draining itself will not supersede the necessity of performing this most necessary operation. The whole valuable effects of ploughing, harrowing, grubbing, &c., may be reduced to this: and almost the whole superiority of garden over field produce is referable to the greater perfection to which this pulverising of the soil can be carried.

"The celebrated Jethro Tull has the honour of having first directed the farmer's attention forcibly to this subject; and so deeply impressed was he with its infinite importance, that he believed the use of manure could be entirely superseded were this pulverising carried to a sufficient extent.

"The whole success of the drill husbandry is owing, in a great measure, to its enabling you to stir up the soil well during the progress of your crop; which stirring up is of no value beyond its effect in more minutely pulverising the soil, increasing, as far as possible, the size and number of the interstitial canals.

"Lest any one should suppose that the contents of these interstitial canals must be so minute that their whole

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amount can be of but little consequence, I may here notice the fact, that in moderately well pulverised soil they amount to no less than one-fourth of the whole bulk of the soil itself; for example, 100 cubic inches of moist soil (that is, of soil in which the pores are filled with water while the canals are filled with air) contain no less than 25 cubic inches of air. According to this calculation, in a field pulverised to the depth of 8 inches, a depth perfectly attainable on most soils by careful tillage, every imperial acre will retain beneath its surface no less than 12,545,280 cubic inches of air. A familiar illustration of the space occupied by the spaces between the particles of loosened soil is afforded by the fact that when soil is disturbed it more than fills the space it previously occupied.

"Taking into calculation the weight of soil, we shall find that with every additional inch which you reduce to powder (by ploughing, for example, 9 inches in place of 8), you call into activity 235 tons of soil, and render it capable of retaining beneath its surface 1,568,160 additional cubic inches of air. And, to take one more element into the calculation, supposing the soil were not properly drained, the sufficient pulverising of an additional inch in depth would increase the escape of water from the surface by upwards of 100 gallons a day.

"The great purpose of draining being, immediately, the improvement of the land, but, ultimately, the promotion and improvement of vegetable production, the preceding considerations as to the fitness of the soil for germination may be well followed by a brief enumeration of the rules for the application of water to plants, which, as laid down by De Candolle, refer—

"First, to the quality of the water used: that it should be well aërated; the presence of atmospheric air is good, but of carbonic acid gas much better. The next qualities desirable are, that it should contain fertilising matters; the water should be as little muddy as possible; the temperature of the water is of importance, especially for hot-house

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plants: the water used in hot-houses is allowed to stand for some time before it is employed, in order that it may have the temperature of the place; it is well that other water employed should stand for a time in the sun.

"Second, to the times of the application:—In the winter time there should be little irrigation, because the plants are then dormant, and water is then superabundant. In spring-time water is usually abundant. In summer it is wanting; and at that time the water should be given in the evening.

"Third, to the quantity of water to be applied, which should be varied according—

"*a.* To the object of the culture:—When for leaves, more water should be given than when for flowers; less water should be given when for grains or fruits.

"*b.* To the depths of the roots:—The application should be more frequent to the plants of which the roots are superficial; less frequent to deeper roots.

"*c.* To the structure of the foliage:—Those which evaporate much (such as plants with large leaves), more frequently than perennials, or plants with thick leaves.

"*d.* To the consistence of the stalks, and of the roots:—Roots with fleshy fibres do not thrive if too abundantly watered; at the same time they are injured by dryness. Tuberculous or bulbous plants, or plants with fleshy leaves, can bear a long-continued dryness, and therefore infrequent, yet abundant waterings, suit them well.

"*e.* To the stage of vegetation:—It is important to bear in mind that young germinating plants require light and frequent waterings; those that are in the height of growth abundant waterings; and when the fruit or seed is being matured the waterings should be infrequent. Those that have been transplanted require abundant watering.

"*f.* To the nature of the soil, according to which these rules must be modified:—The lighter the soil the more frequent and plentiful must be the waterings. If it is a compact and clayey soil less watering will be required.

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"*g*. To the state of the atmosphere:—It will be readily conceived that the watering must be more frequent when the temperature is high, the sky clear, and the air dry, and during drought."

The nature of the several soils which we have to deal with will be best understood by regarding the manner in which they have been formed, and the several materials of which they are constituted. The formation of all soils may be very clearly traced to the disintegration, by mechanical and chemical agencies, of rocks and minerals which contain alkalies and alkaline earths. In the mountainous districts of perpetual snow, the most refractory rocks are crumbled into fragments, which, being rounded by the action of glaciers, or pulverised into dust, are borne down by the rivers and streams, and deposited upon the plains and valleys below. Some of the most remarkable proofs of the influence of the air, water, and carbonic acid upon the constituents of rocks, are exhibited in parts of South America, where the elements of the silver ores are gradually dissolved and dissipated by the action of these agents in the winds and rains, and the metal, resisting the destruction, is left exposed in sharp angular projections from the surface of the rock.*

The yellow clay which occurs so frequently in Denmark is considered by Forchammer to have been formed from granite, the felspar of which has undergone change, while the mica has not; the quartz forming the sand of the clay. The blue clays, having no mica, appear to have been formed from sienite and greenstone. The great stratum of clay which occurs at Halle has resulted from the disintegration of porphyry. Most of the sandstones contain silicates with alkaline bases, and in the sandstone of the Holy Mountain, near Heidelberg, fragments of felspar are observed partly changed into clay, and visible as white points in the sandstone. Felspar is unable to resist the

* Darwin, Liebig, &c.

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solvent action of water when saturated with carbonic acid. Clays formed by the disintegration of felspars containing potash are free from lime; those formed from Labrador spar, which is the principal component of lava and basalt, contain lime and soda. Most rocks, as felspar, basalt, clay, slate, porphyry, and the numerous varieties of the limestone formation, consist of compounds of silica with alumina, lime, potash, soda, iron, and protoxide of manganese; and from the fact that most of these ingredients are susceptible of uniting with oxygen, the cause of the disintegration of the rocks which they constitute may be readily and fairly inferred. Of these constituents, the protoxide of iron has a great disposition to absorb oxygen from the atmosphere, thus forming the higher oxide or peroxide of iron. This property is indicated by the reddish brown colour of the rich ferruginous soils, while the black colour of the subsoil shows the presence of the protoxide. In the process of subsoil-ploughing, this protoxide frequently becomes exposed, and the consequence is that the fertility is impaired until the protoxide is converted into peroxide, and the red colour becomes apparent upon the surface. Struve has proved by experiments, that water which is impregnated with carbonic acid decomposes all rocks containing alkalies, and then dissolves a portion of the alkaline carbonates.

Soils being thus formed by the disintegration of rocks, their properties are evidently dependent, first, upon the nature of the several components of these rocks; and, secondly, upon the effects produced upon these components by the action of the air and water to which they are subsequently exposed. Of the various kinds of soil, the principal constituents are—1, sand, 2, lime, and 3, clay. The first two of these, containing no other inorganic substances except siliceous earth and carbonate or silicate of lime, afford no nutriment whatever for vegetation. The clay or argillaceous earth constitutes the fructifying element in all soils, and is produced by the disintegration of aluminous

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minerals, among which are the felspars, mica, &c. The fertilising properties of argillaceous earths appear to arise from their containing alkalies and alkaline earths, with sulphates and phosphates, ingredients which are never absent from these earths. This valuable property of the argillaceous earths is also aided by the peculiarity of their texture, which affords great facilities for retaining moisture. Vegetable life, however, requires, besides the nourishing properties found in the argillaceous earths, to be supplied with air and moisture, and while alumina gives no aid to the passage of these essentials, chalk and sand do give it by their mechanical formation. Hence, "land of the greatest fertility contains argillaceous earth and other disintegrated minerals, with chalk and sand in such a proportion as to give free access to air and moisture." * The clays are therefore to be regarded by the drainer as impermeable and retentive materials, and the sands and limes as porous materials; and the infinitely varied proportions in which these matters are found combined in soils, determine the degree in which each soil will facilitate or impede the passage of water through it.

* Liebig.

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SECTION II.

Drainage of Lower-lying Districts.—Drainage of Upland Districts.—Arrangement of Drains.—Character of Water.

THE principal division of districts and lands, as subjects for watering and draining, is derived from their relative levels. The sources at command and methods of proceeding for high and low tracts are perfectly dissimilar, and hence the natural and necessary distinction which is adopted as the head of this section. And as the plains and valleys are far more extensive in themselves than the hill tops and uplands, and equally superior in importance as recipients of the drainer's care, it is proper to turn our attention to them in the first instance.

In this first class, the Lower Districts, we propose to include the following varieties of surface, viz.:—1st, the low lands forming the margins of seas and rivers; and 2nd, generally, the valleys in which natural watercourses have been formed, such as rivers, streams, &c.; 3rd, valleys in which lakes, or similar expanses of water, do or might exist, and which, with that adaptation, have a continuously curved or basin-like contour; 4th, and plains which, although they may have a superior elevation to adjacent districts on one side, are correspondingly low in relation to the hills on the other. The sections sketched in the foreground of the Figs. 1 to 4 will illustrate the relationship of levels referred to in each of these four varieties.

The watering and drainage of districts belonging to the first of these varieties (Fig. 1) are frequently reduced to the sufficiently heavy task of getting rid of a large surplus of water which collects from the adjacent estuaries of large

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streams, or is detained in the form of evaporation from the surface of the sea, and condensed by low temperature. If the level of the district is above that of the sea and river-mouths, surface drainage, of properly determined depth and

Fig. 1.—Drainage of Low Lands.

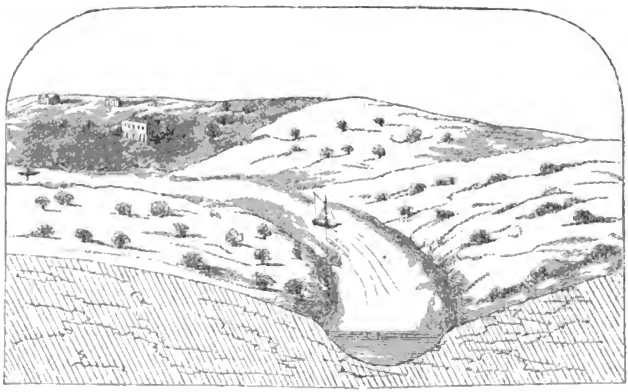

Fig. 2.—Drainage of Valleys.

extent, with ample main conducting channels, will suffice to keep the land in a tolerably dry condition. An opportunity very seldom exists in such dis ricts for tapping, or getting rid of the excess by opening a communication with

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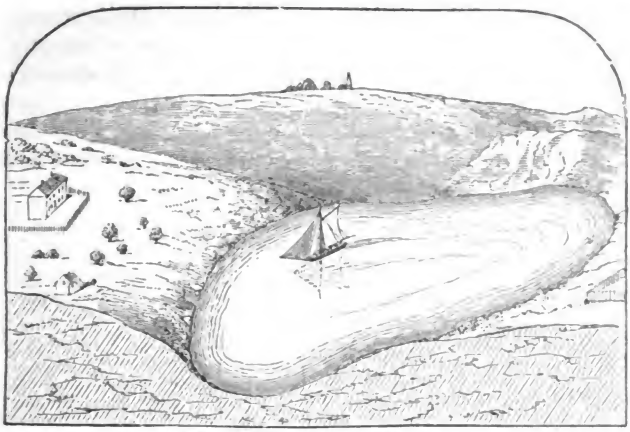

Fig. 3.—Drainage of Basins.

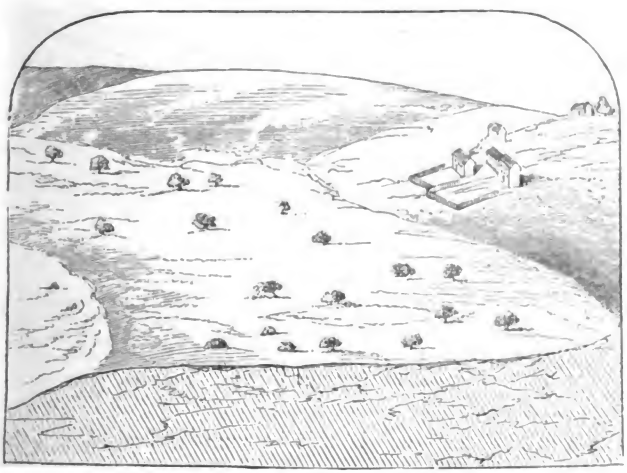

Fig. 4.—Drainage of Intermediate Plains.

a lower and permeable stratum. Rock in some cases, and bog in others, usually form the inferior deposits. If the former, surface draining is certain of success, although the

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construction will probably be expensive; but if the substratum be bog, and its bed below the river or sea level, boring to lower strata is presented as the only chance of success.

Recurring to Fig. 2, p. 28, the districts there illustrated will require methods of drainage determined by the incli-

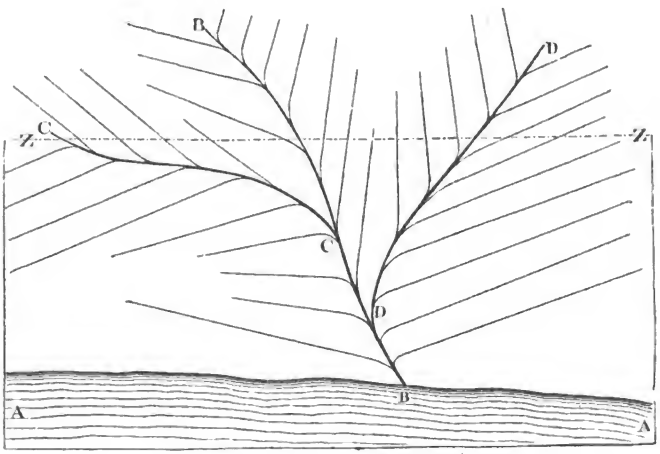

Fig. 5.—Drainage of Valleys.

Fig. 6.—Drainage of Valleys. Section.

nation of the surface. If this be comparatively level, the drains may be generally cut with beds parallel, or nearly so, to the surface, and arranged to deliver into one or more main drains having lower beds, but still above the low-water level of the river or receiving channel, and from which the water can be let off when the tide is down, by providing

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sluices suitable for the purpose. If the surface undulate, the main drains must be laid in the hollows, and the feeders be distributed over the higher parts, and made to communicate with the mains. Small sluices fixed at intervals both in the main and minor drains, will, by intercepting

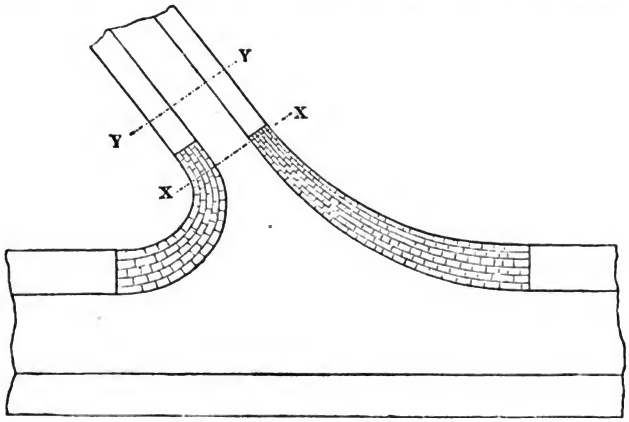

Fig. 7.—Junction of Drains.

Fig. 8.—Section of Drain.

Fig. 9.—Section of Drain through the guard walls.

the water, permit an accumulation when desired for flooding or irrigating the higher lands. Figs. 5 and 6 show a plan and section of a district of this character. A A is the river or receiving channel; B B the principal main drain; and C C and D D two other main drains delivering into it; each of the mains receiving the drainage from the feeders

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or minor drains. Fig. 6 is a section supposed to be taken on the line z z on the plan. Two imperative rules require to be observed in these arrangements, viz. that all the junctions shall be curved, and that no two feeders shall enter the main drain at opposite points. If these rules are neglected the currents will be interrupted at these points, and mischief may arise from flooding when the drains become filled in wet seasons. It is also advisable, if the ground be of a loose texture, to guard the junctions with a few rough stones piled together in the form of a retaining wall; or, for greater permanence, concreted with lime and gravel, as shown in the plan and sections, Figs. 7, 8, and 9, of which Fig. 7 is a plan, Fig. 8 a section through the ordinary drain taken on the line Y Y, and Fig. 9 a section through the guard walls, taken on the line X X.

If the general inclination of the surface of the district be considerable, it is often desirable to form catch-water drains, or series of drains at different elevations, communicating with each lower one successively by falls. By this method great facilities are obtained for regulating the management of the waters, so that any required quantity can be retained to compensate for seasons of drought; while, moreover, the falls are applicable as water-power, and may be used for a variety of purposes. Fig. 10 is a plan, and Fig. 11 a section of a district drained in this manner. A A, B B, and C C, are the main or catch-water drains, each of which receives the drainage from the minor drains or feeders connected with it, and delivers it to the next lower main, through the channels *a a*, *b b*, and *c c*, each of which has sluices fitted to it, while the water forms a series of falls at the points marked *y*. Or the water from the superior levels may be received in reservoirs constructed for the purpose and in the places of the catch-water drains, and there disposed of for agricultural, manufacturing, or domestic purposes.

In Fig. 3, p. 29, we have sketched an inland body of water, or lake, which receives the drainage of the ad-

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jacent districts, and to these, thus situated, the same methods of draining as those just described are generally applicable.

The several methods of draining, as already explained in reference to Figs. 1, 2, and 3, are also more or less

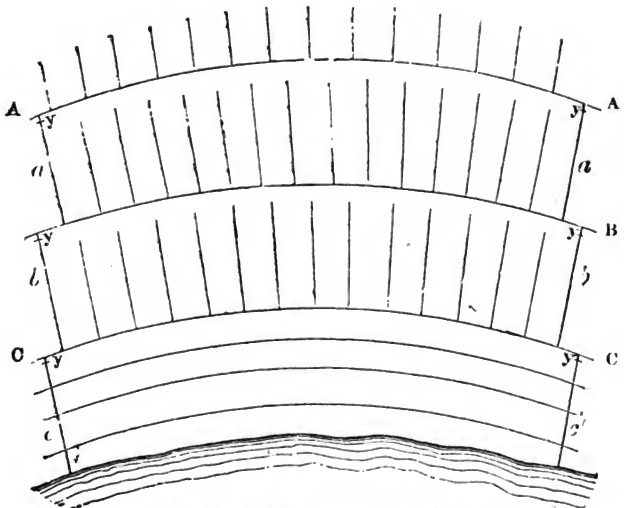

Fig. 10.—Catch-water Drains.

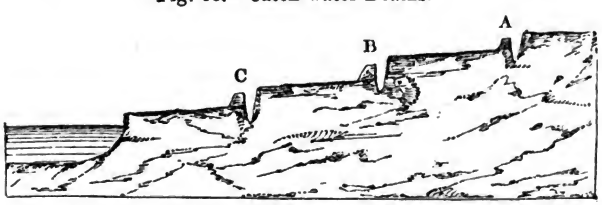

Fig. 11.—Catch-water Drains.

applicable for districts of the kind sketched in Fig. 4, and also for the second class, or Upland Districts. Thus, the drainage from the high lands has to be received and collected in catch-water drains at the base of the hills, and means taken for combining these waters with those from

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the level district, or for keeping them separate, as may be required. Or reservoirs may be formed in connection with the catch-water drains, so that irrigation may not be necessarily suspended in cases of drought or deficiency of rain water

Upland districts are liable (even with all the aid that can be rendered by economy of the natural supply) to suffer from an inadequate command of water. Thus if, as shown in Fig. 12, the surface of the district A A have a stratum of clay or other impervious material, B B, immediately beneath it, the outer stratum will remain always comparatively dry, the rain and drainage waters eagerly

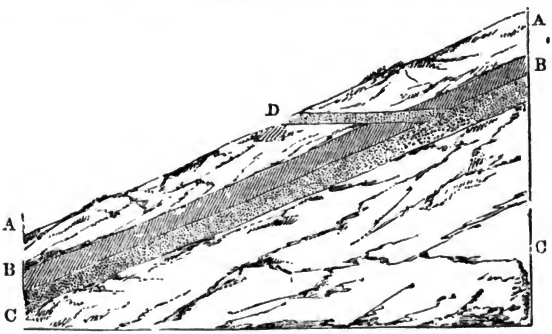

Fig. 12.—Upland Districts.

flowing downward, while the clay resists their passage into the subsoil. Beneath the resisting layer, however, a permeable and saturated soil, as C C, is often situated, and in these cases an adit drain at D, or other convenient point, will bring the internal water to the surface, and probably aid the supply of the district with the drainage waters from a higher and overcharged level. Internal springs are also, in some cases, available for this purpose, and may be brought into use by simple and inexpensive means. If these resources fail, it may become desirable to apply mechanical power for raising the necessary quantity of water from a river or other reservoir at a lower level.

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With a knowledge of soils, we may proceed to the arrangement of the drains required for regulating the supply of water to the lands of a district. This arrangement will be varied according to the contour of the surface, and the position of the substrata. If this be level, and the texture of the soil uniform, the drains may be at once planned, with mains at certain intervals, and minor drains or feeders at right angles to the mains, and parallel among themselves, as shown in Fig. 13. The inclination in the

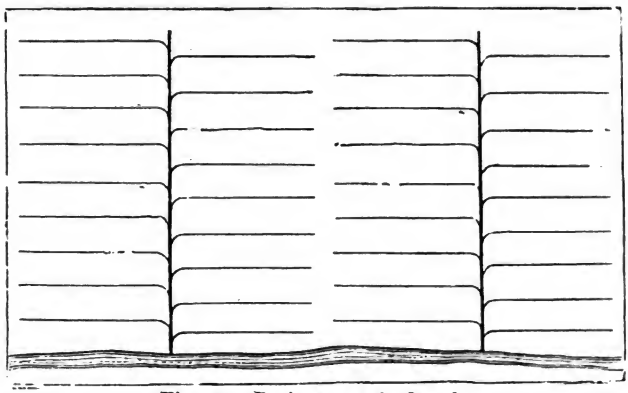

Fig. 13.—Drainage on the Level.

bed of the drains, which is necessary to assist the discharge of their contents, must be obtained by cutting them deeper towards the receiving channel, as shown in Fig. 14, which

Fig. 14.—Drainage on the Level. Section.

is a longitudinal section of one of the main drains, with the feeders discharging into it. This increase of depth also provides the additional capacity wanted in the drains as the water accumulates in them. An undulating surface will require the main drains to be arranged at the lowest

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levels, and the minor channels conducted into them with due reference to the capacity of the mains to discharge their united contents. Fig. 15 is a plan of a surface of this kind, the lines A B, C D, and E F, showing the position of the hollows in which the main drains are to be laid, the minor ones being arranged so as to divide the total discharge among the mains as nearly equally as the nature of

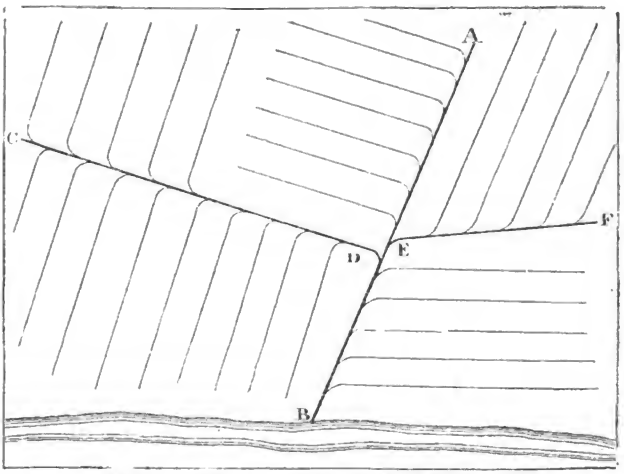

Fig. 15.—Drainage of Undulating Surfaces.

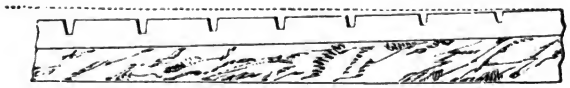

Fig. 16.—Undulating Surfaces. Section.

the surface will conveniently admit. The capacity of the mains, as also of the feeders, must, of course, be determined according to the quantity of water for which passage is required, and modified also by the steepness of the fall. If the fall is considerable, a drain of smaller dimensions will suffice than will be necessary if but little inclination can be obtained. That part of the main drain from E to B

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will, in any case, require enlarged capacity, as it receives the entire drainage. Fig. 16 is a section of part of the mains, in which it will be seen that, as the surface inclines, the bed of the drain will have sufficient fall if laid at equal depth from the surface of the ground throughout. The drains are arranged parallel to each other, which is evi-

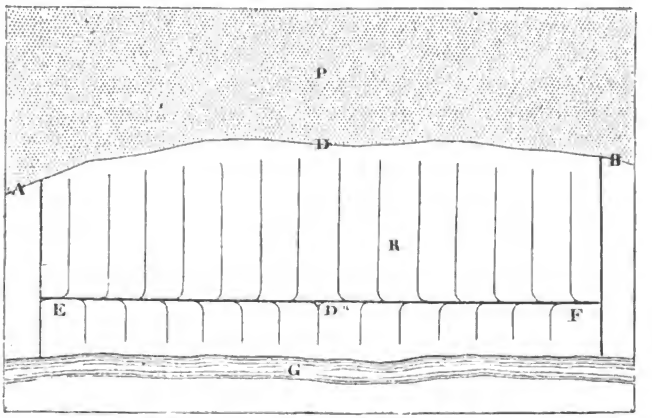

Fig. 17.—Drainage of Differing Soils.

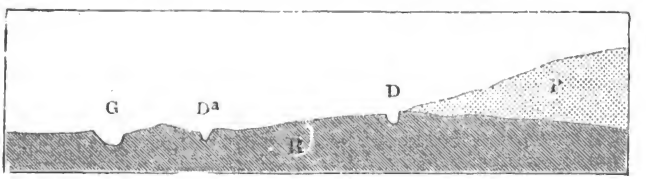

Fig. 18.—Differing Soils. Section.

dently a good rule where it can be observed, the surface being thus divided into equal spaces, and the drainage made at once perfect and simple.

The arrangements of drains here described suppose the texture of the soil to be the same throughout the surface to be drained; but if soils of different retentive power appear upon the surface, it becomes essential to arrange

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the drains with reference to the line of junction of the soils. Thus, let Figs. 17 and 18 represent the plan and section of a district whereof the higher ground is of porous materials, P, overlying the clay, or other retentive soil (marked R), as far as the line A, D, B, where the clay first appears upon the surface. The water, percolating through the bed P, and prevented from descending by the clay, will accumulate along the line A, D, B, and form a swamp unless got rid of. In this case, therefore, a drain must be laid along this line, while a main drain for the remainder of the ground, which slopes towards the brook at G, must be formed on the line E, D^a, F. This latter drain receives the contents of the minor drains, which are to be laid parallel, as shown in Fig. 17. The upper drain, A, D, B, discharges into the brook G by the cross ducts A E and B F. The two main drains must, if the surface permit it, be laid with their beds dipping either way from the middle at D and D^a, so as to insure the free passage of the drainage water.

The general arrangement of the drains being, as already stated, controlled by the superficial contour and texture of the soil, cannot be properly determined without reference to the sectional strata of the district. If these consist of materials of various degrees of porosity, their relative positions, not only on the surface, wherever the substrata may outcrop, but also in the section, must be regarded. In this kind of consideration consists one great field in which so much improvement has been already effected, and so much more may be, in the practical art of land-draining.

Proceeding to an examination of the several varieties of the structure of soils which are met with, we propose to consider the strata under the three leading characters, as exhibited in the following diagram, viz. the porous, or readily permeable; the retentive, or comparatively impervious; and the semi-porous, or mixed.

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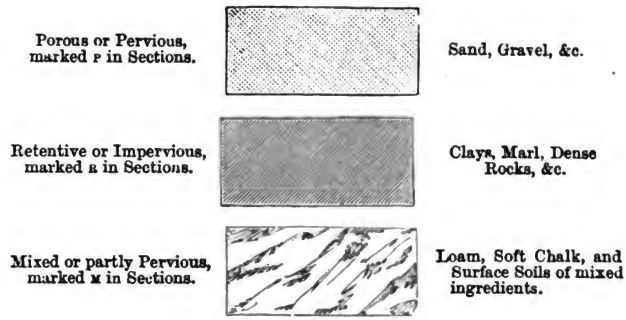
Characters of Strata.



This diagram, therefore, will serve as an index to the several sequent illustrations, numbered from 19 to 32 inclusive.

In Fig. 19 we have a common arrangement of strata, the

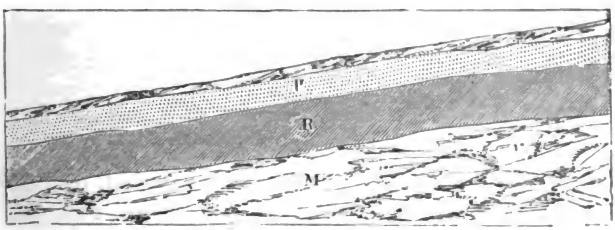


Fig. 19.—Surface-soil on a Porous Stratum.

surface-soil (which for its thinness need not be regarded), on a porous stratum, and this lying upon a retentive one. The method to be adopted, in this case, will partly depend upon the thickness of the several strata. The water falling upon the surface will saturate the supersoil, and, being impeded by the lower stratum, will not pass away except by frequent drains, arranged with regard to the inclinations of the surface. If the clay beneath be of considerable thickness, so that the average depth of its bed from the surface exceeds 5 ft., it will be economical to limit the

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depth of the drains to the upper stratum, and thus avoid interference with the clay. The land, however, will be brought into a drier condition by penetrating the clay, with the main drains at least. But, by doing so, if springs exist below the clay, they may thus become exposed, and the work of drainage thereby augmented. Borings should, therefore, be made along the lines of lowest surface, and especially at any points where wet appears to gather, and, if any springs are thus detected immediately below the clay, they should be tapped, that is, have communications opened to the drain, so that their contents may pass away through the proper channels.

When the porous bed is beneath the clay or retentive bed, as shown in Fig. 20, it will be advisable to cut the

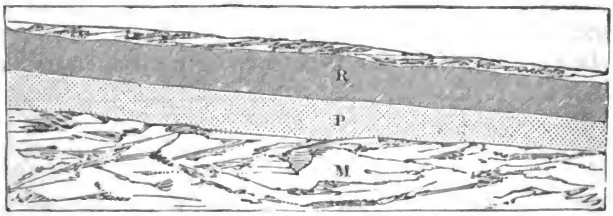

Fig. 20.—Porous Bed beneath Clay.

drains through the clay into the lower stratum, provided the latter is of sufficient depth to bear the water, and assist the drainage of the district. Supposing the entire depth of the lower bed from the surface does not exceed 6 ft., and it be desirable to economise the water for subsequent irrigation, or other purposes, it will be well to cut the drains completely through both strata, and thus clear off the whole of the subwater, as well as that from the immediate surface. This arrangement of strata requires the drains to be laid at small intervals, and of ample capacity, as the dense supersoil will keep all the water which falls upon it, and also that which reaches it from superior levels. Some beds of clay are of such thickness that no practicable drains can be made to communicate with the substrata. When this

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is the case, the general system of drainage should consist of small drains laid very closely, so that the worked mass of clay may become thoroughly freed from an excess of water.

Fig. 21 represents a similar succession of strata to those shown in Fig. 19, viz. the surface-soil resting upon a porous bed, and this upon one of a retentive character. But the contour of the surface is such, that the main drains must be formed in the middle of the section, which is the lowest

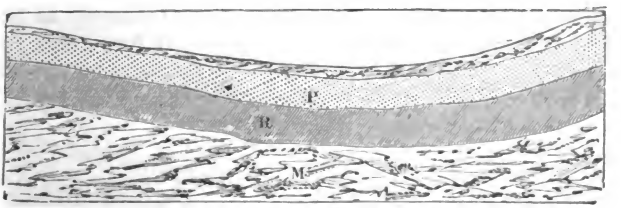

Fig. 21.—Porous Bed on Clay.

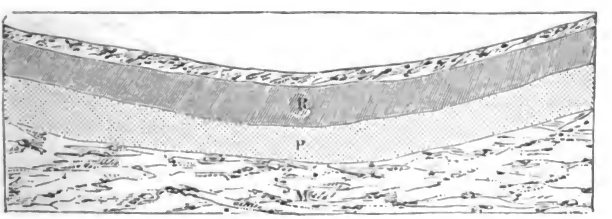

Fig. 22.—Porous Bed below Clay—Concave Surface.

part in the case here illustrated. The substratum of clay, rejecting the water, assists its accumulation at the point marked P, and it will become necessary to provide a drain of large dimensions in proportion to the extent of the district to be served. If the general surface is favourable, it will be better to arrange the principal number and extent of drains at right angles to the section, as here shown, rather than parallel with it. The main central drain will be thus relieved of the violence of the rapid discharges

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which the steep drains would send into it, and less danger will accrue from floods descending from the higher lands.

An arrangement of strata, which is very apt to discover springs rising to the surface, is shown in Fig. 22, in which the district appears to have a concave surface, with the porous stratum occupying the lower position. The water contained in the higher portions of this bed will burst forth at any outlets that may be formed through the clay; and indeed, if the latter be not of great depth, it will frequently force passages for itself, and thus augment the lower surface accumulations, which are collected at the middle of the section in consequence of its form, and the

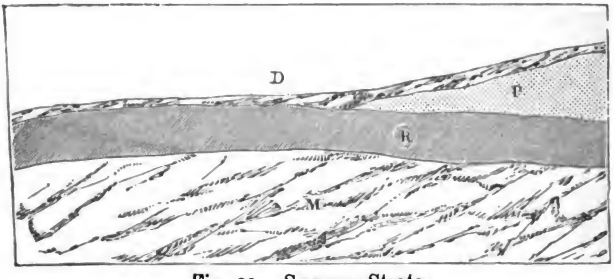

Fig. 23.—Swampy Strata.

density of the upper clay. Efficient drainage will, in this case, require that the channels intersect the porous stratum, and, if the depth be not too great, the beds of the drains should reach that of the stratum. The position of the drains on the plan should also be determined with a view to cut off the water from the gravelly bed at the higher parts of the section, and thus relieve the central main drain at R, which would otherwise become overloaded. Three main drains, therefore, or more, if the sides of the basin be of great extent, should be laid, viz. one at the middle of the section, and two at the higher part, on either side of, and parallel with it.

In Fig. 23, the strata are represented in positions which

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produce swamps or morasses. Thus, at the point D, at the foot of a porous bed, lying upon one of clay, which rises from that point, the accumulation of water will require a main drain to be laid, bounding the base of the permeable stratum throughout the entire district, and to have a capacity in proportion to the extent of that stratum. If the clay be of inconsiderable thickness, the main drains should

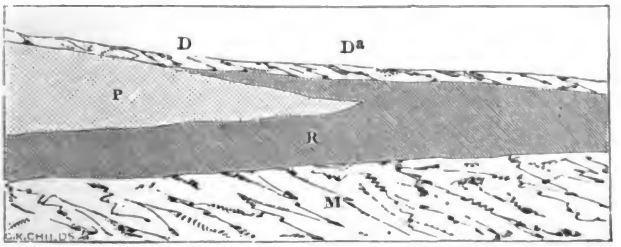

Fig. 24.—Swampy Strata.

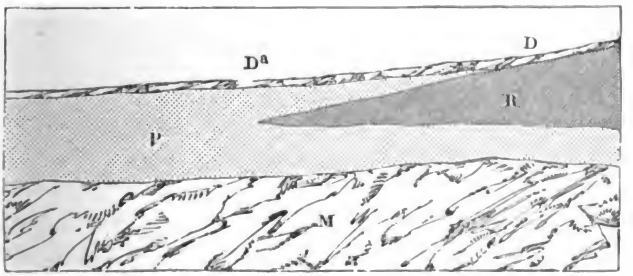

Fig. 25.—Swampy Strata.

intersect it completely. In this arrangement it will be manifestly useless to cut channels *above* the point D, except as shallow feeders to the mains. This section illustrates one of the reasons of the failure of the methods formerly adopted of attempted drainage without consulting the structural condition of the soil.

Sometimes a tongue of gravel, or other pervious material, will be found to extend into and under the clay, as

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shown in Fig. 24, in which a main drain at D, whatever its dimensions may be, will not be sufficient to intercept the drainage water which passes through the bed, and will require another main at D^a. In this case, indeed, the principal drain should be laid at this point; otherwise, that portion of the district lying between D and D^a will remain in a moist and swampy state.

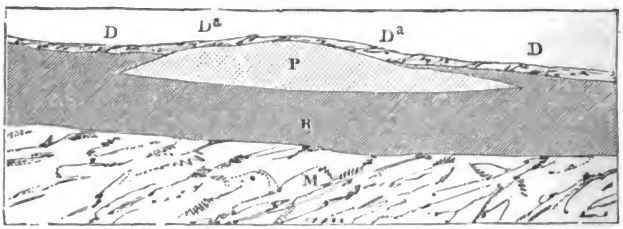

Fig. 26.—Gravel on Clay.

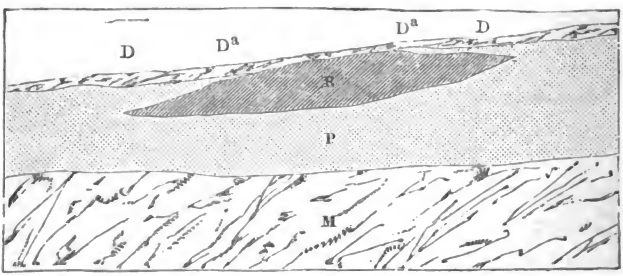

Fig. 27.—Clay on Gravel.

If, however, the position of the strata be reversed, and the clay runs into and beneath the porous material, as represented in Fig. 25, the main drain at D should, if practicable, be cut through the clay, so that the water may be assisted in draining from it, and keeping the space from D to D^a in a healthy condition. At the latter point, the depth of the main should be such as to reach the bed of the clay, and prevent the water running back towards the point R,

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in case the inclination has a tendency to produce that effect.

A patch of gravel or similar material is occasionally met with in the midst of a district, the surface of which, in other parts, consists of clay, as shown in Fig. 26. In this case two sets of drains will be required, viz. at the points D D and D^a D^a; and the same remarks as to the relative

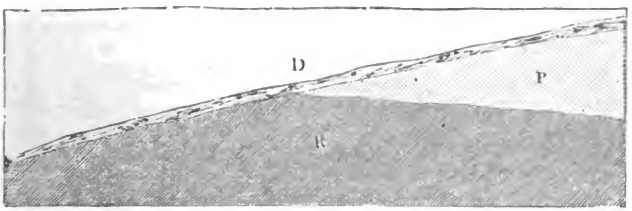

Fig. 28.—Inclined Surface.

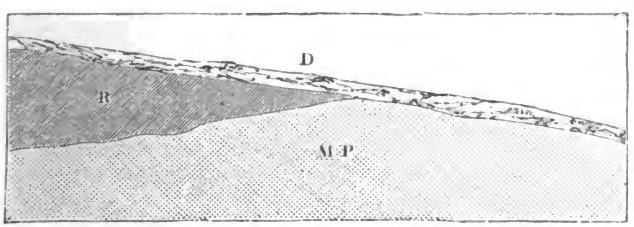

Fig. 29.—Inclined Surface.

depths of these mains will apply as already made in referring to Fig. 24.

Fig. 27 shows a similar patch of clay running into and under the gravel, requiring also two sets of main drains, which will be more effective in proportion to their depth, and the most so if they reach the bed of the clay, and thus prevent its injurious retention of the drainage water from the gravel or sand overlying its edges.

When the general surface of the district has a considerable inclination, as shown in Figs. 28 and 29, the methods of drainage to be adopted will be varied according to the relative positions of the materials. Thus, if the porous

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material be above, as in Fig. 28, the main drain should be at the point D; but, if the clay lie upon a stratum of less density, as in Fig. 29, the main should be laid at a lower situation, where it will naturally receive all the water which accumulates at D, besides that contained in so much of the lower bed as is above it.

If a bed of gravel lie in the hollow of a stratum of clay,

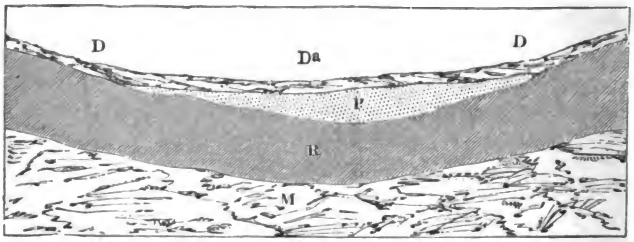

Fig. 30.—Gravel on Clay—Concave Surface.

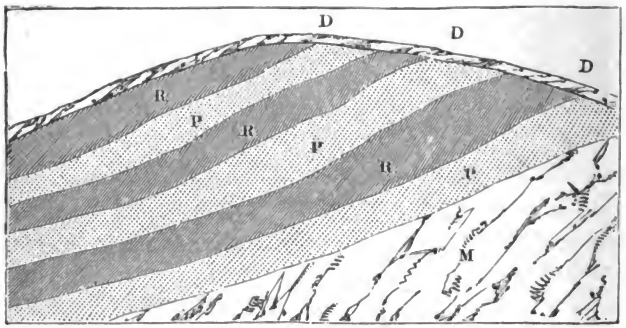

Fig. 31.—Clay and Gravel alternating.

as represented in Fig. 30, the surface of the district will remain tolerably dry except at the lowest point Da, where the accumulation of water from the higher parts, resisted in its disposition to descend by the substratum of dense texture, will make a principal main drain of ample dimensions necessary. Auxiliary mains are also required at D, D, to drain the clay surface above these points, and save the

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porous bed from the saturation which will naturally occur unless thus prevented.

In hilly districts, clays and gravel are often found in alternate layers, which outcrop on one side of the hill, as sketched in Fig. 31, and render a series of main drains necessary at the points marked D. By these drains, the water which gathers in the retentive strata will be discharged at the lowest points on the surface, and prevent any mischievous excess on the soil. The intermediate

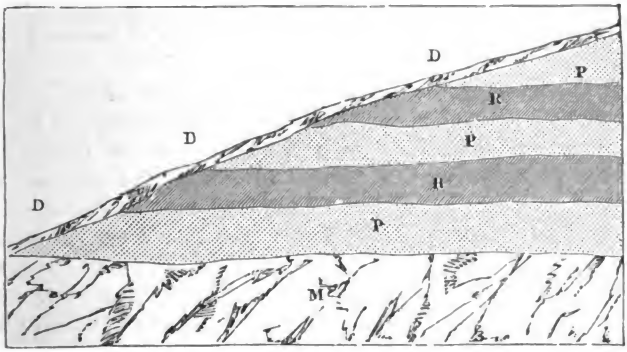

Fig. 32.—Clay and Gravel alternating.

portions of the porous materials which are exposed will readily get rid of their contents by percolation, and drains of comparatively small dimensions will be adequate to the efficient drainage of a section thus composed.

Sometimes the side of a hill displays a series of alternate and horizontal layers, as represented in Fig. 32, in which case a small main drain should be laid at the exposed bed of each stratum, at the points marked D, D, which will receive the contents of each porous layer, and prevent any injurious excess accumulating within the intermediate clays.

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SECTION III.

Drainage of Fen Districts.—Ancholme Drainage.—Sections of Drains. — Embankments. — Rectification of Rivers. — Reclamation. — Draining Scoops.—Steam Power.—Drainage of the Lake of Haarlem.

If the level of the district be below that of the contiguous waters, it is manifestly impossible to dry the land without embanking. And it is necessary either that this work be sufficiently substantial to prevent the ingress of water, or that the surface of the land be simultaneously raised artificially until it has a superior level, or that mechanical means be constantly employed to pump out the surplus water. Our own island has been preserved in its borders, nay, extended, by works of this class, which we shall now have to notice.

It was upon districts such as those we are now considering that the art of draining was first practised. Here the matter was one of obvious necessity. In wet fields and moist pastures, our ancestors found no positive demand for improvement; the evil was seen and recognised in its full extent, but the only tangible effect was to depreciate the value of the land, and induce a preference for districts where nature provided a more sufficient drainage. But on the sea-coast, and especially in the neighbourhood of the outfalls of rivers, the evil of neglect was too apparent to be disregarded; the ocean spread over its common bounds, and the waters of the river, choked up with silt, passed their limits, the pasture fields became swamps—in some cases the land disappeared by degrees, and the inheritance of ages became merged in the boundless waters.

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The first work was to cut channels at intervals through the threatened district (selecting the lowest levels for them, where a choice was afforded), in which the excess of water might be collected and conducted to a main drain cut parallel to, or at an angle with, the coast or river; the transfer of the water from one to the other, and from the main to the sea or river, being, when necessary, regulated by sluices. The earth removed from these collecting and main drains, being cast up on either side of them, at once increased their available depth, formed boundaries to the passing water, and raised causeways for the passage of men and animals. Thus arose the combined arts of draining and embanking.

The maps of the fens of Cambridgeshire and Lincolnshire exhibit a multitude of illustrations of the works here referred to; but we may select those executed in one district as examples of the whole. This district consists of the lowland or level about the river Ancholme in Lincolnshire, and is situated on the south side of the river Humber, about 10 miles below its junction with the river Trent, containing about 50,000 acres of land. It is bounded on the east by a ridge of chalk hills, which extend from the Humber nearly 24 miles N. and S. From this ridge the Ancholme receives the drainage of about 100,000 acres. A lower ridge of oolite and sandy limestone divides it on the W. from the Trent Valley, and contributes to the Ancholme the drainage of some 50,000 acres more, and on the S. a low diluvial ridge divides the district from the Witham Valley. The Ancholme thus receives the drainage of a total of 200,000 acres. The valley varies from one to three miles in width, and the total bulk of waters daily poured through the river is estimated at 140 millions of cubic feet, being sufficient to cover the entire level to a depth of 2¼ inches. The principal portion of the district lies below the level of high water spring tides in the Humber, being in some places as much as 9 feet below that level. From a map of the valley published in Dugdale, and bearing

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Fig. 33.—Ancholme Drainage.

Fig. 34.—Section.

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date 1640, it appears that the course of the Ancholme was originally very tortuous, being probably enfeebled and choked up by the alluvial deposits from the overflowing of the Humber. At that time, however, a straight channel had been cut, extending from the Humber to Glentham Bridge (a distance of 18 miles), and several drains formed, leading to the new channel. Figs. 33 and 34, which are reduced sketches of the plan and section given by Dugdale, show the general direction of the old and new channels, and the drains as they existed in 1640. In the previous year Sir John Munson became the undertaker for improving the draining works of this district, having a period of six years allotted for their execution, and a part of the lands, extending to 5,827 acres, assigned to him, free of all commons, titles, charges, interest, and demand, of all or any persons whatsoever.

In the year 1801, the late Mr. Rennie reported upon the best means of completing the drainage and navigation of the level; and recommended that the drainage of the high lands should be separated from that of the low lands by main drains, commonly called catch-water drains, formed at a higher level than the others, and arranged with separate sluices for discharging into the Humber. This recommendation was well founded on the observation that the greater force and rapidity with which the waters from the upper district reached the river than those from the lower, had the effect of driving the latter over the level, the sluices being inadequate to discharge the entire bulk of water during the periods while the river-tide permitted the sluice doors to remain open. Another and highly important purpose which the catch-water drains fulfil, is that of providing a reserve supply of water which, during dry seasons, may be applied to the lower lands, thus promoting in those districts the objects which are usually associated with drainage, viz. irrigation and navigation. Mr. Renien had already adopted a similar system of drainage on a more extensive district, that of the East, West, and Wildmore

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Fens, near Boston; but his Report upon the Ancholme level was not then adopted. Twenty-four years later, however, an Act was obtained, viz. in 1825, for effecting improvements recommended by Sir John Rennie, and comprising the formation of the catch-water drains, as proposed by his father in 1801. Sir J. Rennie advised that the river Ancholme should be straightened, widened, and deepened, so as to double its capacity; that a new sluice be formed at Ferraby, having its cill 6 feet lower than the

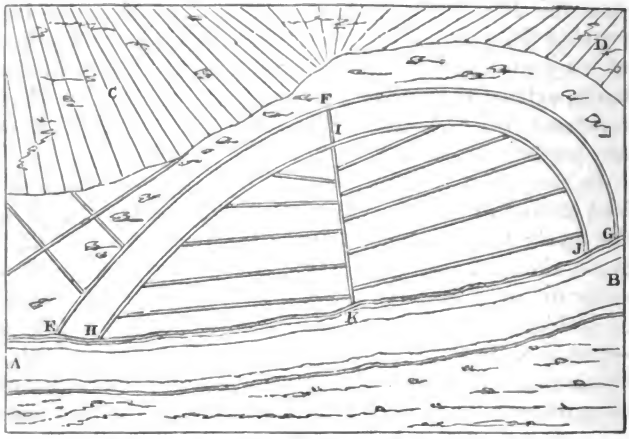

Fig. 35.—Level District backed by High Land.

old one; together with a new lock, 20 feet wide, so as to serve the double purpose of admitting larger vessels, and affording a greater discharge for the drainage waters during floods; that all old bridges which obstructed the flow should be removed, and a new lock be formed 18 miles above Ferraby sluice. These several works were executed accordingly, and the entire level of Ancholme has been converted into a rich arable district, capable of producing superior crops of every kind. Sir John Rennie also recommended the formation of reservoirs, with overfalls

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and weirs to receive the sand and mud brought down from the upper part of the country, and thus prevent its accumulation in the river.

Fig. 35 will give a general idea of an arrangement of drains, which will be suitable for a level district with high land behind it. In this figure, A B is the river, and C D the high land. E F G represent a catch-water drain for receiving the waters from the high land; H I J, a parallel main drain for the level, with another main drain I K. Between

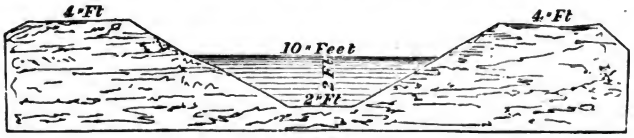

Fig. 36.—Drain of Large Size.

Fig. 37.—Drain of Large Size.

Fig. 38.—Drain of Large Size.

the main drains the level is intersected with minor drains, which have a fall either way towards the mains. The catch-water drain is adapted to discharge directly into the river; or by closed sluices at E G, and an open one at F, its contents may be directed into the main level drain at I, and made to assist the irrigation at the level in dry seasons. Sluices will be required at E, F, G, H, I, J, and K, by the regulation of which the water may be collected and disposed of in any manner required for the preservation and improvement of the district.

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Figs. 36, 37, and 38 represent sections of drains of large size, adapted for works of the kind here referred to. Drains of these sections, formed with a fall of 18 inches per mile, will discharge as follows:—Fig. 36, 10-feet drain, will discharge 1193·4 cubic feet per minute; Fig. 37, 15-feet drain, 2880 cubic feet per minute; and Fig. 38, 18-feet drain, will discharge 4642 cubic feet per minute.

Districts lying below the level of the adjacent river, or so little above it that drains of adequate capacity must have their beds below the water line, necessarily require artificial means of discharging the drainage waters into

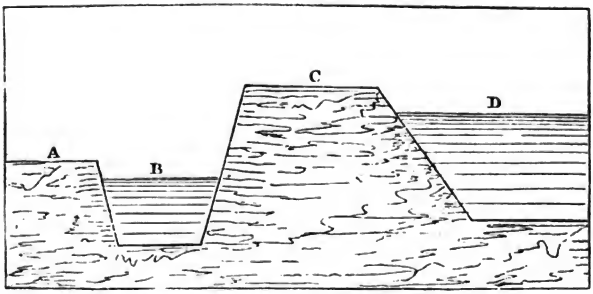

Fig. 39.—Drain next a River.

the receiving channel or river. In the low lands of Holland this is commonly the case, and accordingly we find the Dutch were early adopters of contrivances for this purpose. Fig. 39 shows the relative conditions of the drain and of the river into which its contents are required to be discharged. A represents the general level of the district; B, that of the water in the drain to be discharged; C, the top of embankment; and D, the high-water level outside. To transfer the contents of the drain B into the main channel D, it is evidently only necessary to erect upon the embankment pumps, buckets, or scoops, which shall bring the water up on the one side and discharge it on the other.

A good section for an embankment against the sea for

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these works is shown in Fig. 40, in which A represents the embankment of earth; B, a solid wall or dyke of puddle; C, a facing wall of masonry; D, the high-water level of the sea or bay; and E, the natural bed. The form of the front wall must be adapted to resist the action of the waves, and the embankment must have an internal slope, according to

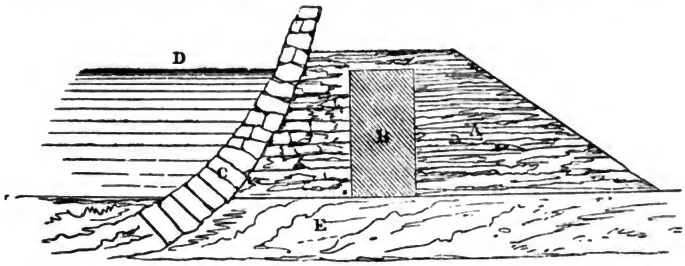

Fig. 40.—Sea Embankment.

the nature of the materials of which it is composed: for ordinary materials a base of 1·5 to a perpendicular height of 1 will insure the necessary stability and firmness.

If the entire embankment be formed of loose stones, with occasional facing only of laid masonry, as in the case

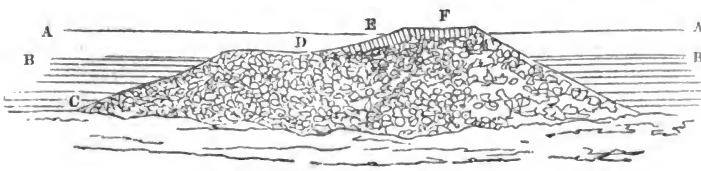

Fig. 41.—Plymouth Breakwater.

of the celebrated breakwater at Plymouth, a form of less steepness must be adopted for the river front of the embankment. By way of illustration we may refer to Fig. 41, which shows a section of the Plymouth breakwater. The line A A shows the level of high-water spring tides; B B, low-water spring tides; C, original bottom, varying from 40 to 45 feet below low-water mark; D, the foreshore; E, sea

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slope; F, top, 45 feet wide. The mass of the work is composed of limestone, from the Overton quarries, distant four miles from the spot. The stone is raised in blocks varying from one quarter to ten tons and upward in weight, which are promiscuously thrown into the sea, care being taken that the greater number of the large blocks are thrown upon the outer or sea slope, and that the whole are so mixed together as to render the mass as solid as possible, the rubbish of the quarry and screenings of lime being flung in occasionally to assist the consolidation of the materials. The form of the outer slope, below low-water line, has been effected by the action of the sea, and is ascertained to be at from 3 to 4 feet of base to 1 of perpendicular altitude. From low water upward the work has been set artificially and inclined at 5 to 1. The inner slope next the land is nearly 2 feet base to 1 altitude. The foreshore shown at D, which is from 30 to 70 ft. wide at different parts of the work, rises from the toe of the slope, to a height of 5 ft. above low water at its outer extremity, and serves to break the waves before they reach the main work; thus diminishing their force, and at the same time preventing the recoil of the wave from undermining the base of the slope.

The several sluices, gates, &c., constructed for the Ancholme drainage, being of the best description, may be briefly described as applicable for similar works in future. The sluice at Ferraby consists of three openings, each 18 ft. wide, with cills 8 ft. below that of the old sluice, and from 2 to 3 ft. below low water of spring tides in the Humber. The lock is 20 ft. wide in the clear, and 80 ft. long between the gates, giving a clear water-way of 74 ft., with an additional fall of 8 ft. The masonry is of best Yorkshire stone; and the foundations, which are in alluvial silt and clay, are upon piles 12 in. diameter, of beech, elm, and fir, from 24 to 28 ft. in length, and fitted with wrought-iron hoops and shoes. When the piles were driven and the heads levelled, the earth was excavated to a depth of 2 ft. below them, and

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the spaces filled with blocks of chalk rammed soundly in, and grouted with lime and sand. Cap-cills of Memel fir, elm, or beech, 12 in. square, were fitted on the pile-heads and firmly spiked down, the intermediate spaces being afterwards filled with solid brickwork, set and grouted with best Roman cement. The whole was then covered with a 3-in. flooring of Baltic fir-plank, bedded in lime, pozzolana, and sand. Inverted arches of solid stonework, 18 in. deep at the crown, are built upon this platform, and the work carried upon them. Two sluice gates were provided for each opening in the sluice, with draw-doors fitted in a water-tight groove by means of pinions of wrought iron, which work in screws connected with vertical rods. These draw-doors are for regulating the navigation level (which is 13 ft. 8 in. above the cill), and to preserve a depth of 8 ft. 9 in. at Brigg, which is 9 miles distant, and 6 ft. 6 in. at Haarlem Hill lock, 18 miles distant. The gates are self-acting, being shut by the tide, and opened by the head of fresh water as soon as the tide falls below the level of the inside water. Four pairs of lock-gates were provided for the lock, two pairs pointing to the sea, and of sufficient height to exclude the highest tides; the other two pairs, pointing to the land, are high enough to control the navigation of the level. These gates were wholly constructed of the best English oak, well fitted together with wrought-iron straps and bolts. The lock is filled and emptied through side culverts in the masonry, provided with cast-iron sluices sliding upon brass faces, and worked with pinions and screws of wrought-iron. The works also included several bridges of various spans and forms of construction.

In the application of catch-water drains it is preferable to discharge their contents at a higher point of the river, or main receiving channel, than that at which the lowland drains are emptied. This principle was very successfully adopted by the late Mr. Rennie, in the drainage of the East, West, and Wildmore Fens, bordering on the

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river Witham, and comprising about 75,000 acres. The drain for the high land waters was made to discharge into the Witham, at a distance of three miles above the discharge of the low land waters.

The drainage of a low fenny district being arranged as far as the judicious selection of separate channels for the high and low lands, and provision made, with sluices, &c., for their communication with each other and with the river at pleasure, it remains to consider the state in which this river must be maintained in order to give efficiency to the internal system of drains by which the district is traversed. For this purpose it is evidently necessary that the channel be adequate in dimensions and suitable in form to maintain an active and sufficient current through it, and these conditions require a direct course and proper fall for the channel. If the direction be tortuous, the projecting banks will be washed into the bed and impede the flow of the current, and if the bed be on a dead level, or have an inadequate inclination, the flow will be sluggish, and lend no assistance to the discharge. Besides these conditions, it is necessary that the outfall of the river into the sea be of ample dimensions and unencumbered with shoals, bars, or other solid accumulations. These arise from the depositions of alluvial matter, which is liable to be brought in by the tides from the neighbouring coast, and also brought down with the drain-water from the interior country. This matter remains suspended in the water until the velocity is diminished, which generally occurs at the entrance to the river, owing jointly to the reduced inclination of the river bed near the sea, and the resistance suffered from the wind and waves, and it is then deposited, and by continual augmentation forms a fatal obstruction to the efficiency of the current. To determine the precise fall or inclination required for the bed of the channel, many experiments have been tried, but it will evidently be, to a considerable extent, controlled by the obstructions which may exist to the discharge of the waters. If the outfall be unimpeded,

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4 inches or 5 inches per mile will be sufficient fall, but if obstructions exist, in the form of old bridges, sinuosities, &c., from 12 inches to 18 inches per mile will be found requisite.

Among the notable works of this kind which have been executed in this country, we may mention those for improving the rivers Ouse and Nene. The chief defect in the former existed above the town of Lynn, where the river turned almost at right angles to its general course, and in a length of 5½ miles formed a semicircle of only 2¾ miles in diameter. The channel was, moreover, so irregular in width and encumbered with shifting sands, that the tidal and drainage waters were unable to force a passage, and disastrous inundations were the results. In the year 1724 this evil was understood, and a proposition made by Bridgeman for improving the river by making a direct cut which should intercept the bend here described. Succeeding engineers concurred in this recommendation; but it was not until the year 1817 that an Act was obtained for executing this important work, which was named the Eau Brink Cut, and confided to the late Mr. Rennie. The works were finished on the 19th July, 1821, and have proved highly successful, lowering the low-water line in the river several feet, and completing the drainage of more than 300,000 acres of land.* A work of similar character was executed in the year 1829, by Telford and Rennie, at the outfall of the river Nene, which commences about five miles below Wisbeach, and terminates after a length of five miles in the great estuary of the Wash. The benefits of this improvement have been very great; the low-water mark has been lowered 10 feet 6 inches, and a district of more than 100,000 acres, formerly a stagnant marsh, has been brought into cultivation.

Closely allied with the drainage of low lands are the operations by which their boundaries are extended, and

* The Great Level of the Fens contains about 680,000 acres, formerly of little value, but now rich in corn and cattle.

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large districts actually reclaimed from the action of the sea. This is effected by judiciously controlling the deposit of the alluvial materials which are washed down with the drainage waters and thrown back by the tide. This requires the formation of embankments of opposing barriers, by which the removal of those materials is prevented. A similar artificial mode of depositing the solid matter contained in the water is practised in the interior districts by surrounding them with embankments, and admitting and discharging the water by means of sluices and canals. This method has for many years been adopted with great success in the rivers Trent, Ouse, and Humber.

Among the earlier machines employed by the Dutch for lifting water were scoop wheels, which they worked by means of windmills, and continued to use for many ages.

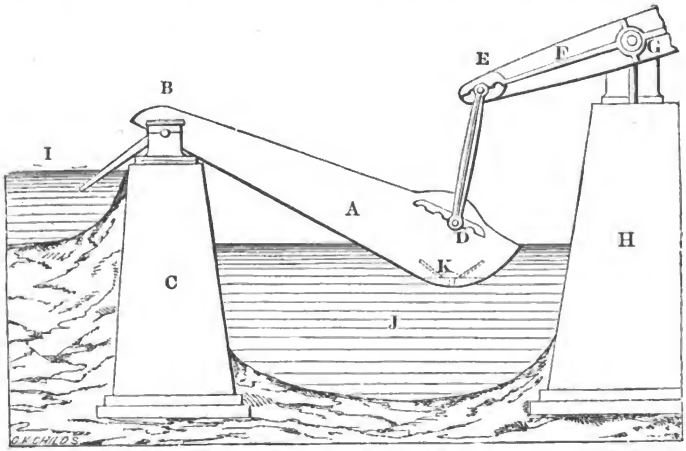

Fig. 42.—Scoop for Lifting Water.

A form of scoop or alternating trough was designed by Sir Wm. Fairbairn, and adapted to be worked by the single-acting Cornish engine. Fig. 42 will serve to give a general idea of this contrivance. A is the bail scoop,

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turning on a centre at B, fixed on the embankment C. The other end of the scoop is connected at D by a connecting-rod with the end E, of the engine-beam F, of which G is the centre, and erected upon suitable foundations, H. I represents the level of water in the river, and J, the drain from which the water is to be discharged. The action of the apparatus will be evident from inspection of the figure. The engine employed is of the reciprocating kind, and by raising a weight suspended at the other end of the engine-beam F, the bailing scoop A descends, and becomes filled with the drainage water through the opening valves at K. The weight having been raised to the height of the stroke, descends by its own gravity, and raising the end, D, of the scoop, discharges its contents into the river at I. This apparatus is well adapted to be worked by the single-acting Cornish engine, and while the length of stroke in the cylinder always remains the same, the dip is regulated as required by shifting the connecting-rod at the ends D and E. The scoop is made of iron boiler plates, and is 25 feet long and 30 feet wide, with two partitions across it to strengthen the sides and afford bearings for the valves at K. The machine is adapted to raise 17 tons of water at each stroke, and, with an engine of 60-horse power, will do a duty equal to 3 lbs. of coal, per horse power, per hour.

The greatest improvement, however, effected in mechanical draining is by the employment of the steam engine for this purpose. In the year 1820, Rennie applied one of Watt's engines to the working of a large scoop wheel for draining Bottisham Fen, near Ely. Since that time large districts have been efficiently drained by steam power; and of them we may enumerate the following:—

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TABLE VII.—Drainage by Steam Power.

	Containing	Drained by	
	Acres.	Engines.	Horse-power.
Deeping Fen, near Spalding, Lincolnshire	25,000	2	80 and 60
Marsh West Fen, Cambridgeshire	3630	1	40 ,,
Misserton Moss, with Everton and Graingeley Carrs	6000	1	40 ,,
Littleport Fen, near Ely (75 wind engines were employed in this district before steam was used.)	28,000	2	30 and 40
Middle Fen, Cambridgeshire	7000	1	60 ,,
Waterbeach Level, between Ely and Cambridge	5000	1	60 ,,
Magdalen Fen, near Lynn, Norfolk	4000	1	40 ,,
March Fen district, Cambridge	2700	1	30 ,,
Feltwell Fen, near Brandon	2400	1	20 ,,
Soham Mere, Cambridgeshire (Formerly a lake; the lift is here very great.)	1600	1	40 ,,

If the drainage from the high lands be discharged through catch-water drains, that from the low levels will consist of the rain water only, and as this seldom exceeds the average of 26 inches in depth per annum, of which a large quantity is carried off by evaporations and absorption, 2 inches in depth or 1½ cubic feet of water on every square yard of surface is the ordinary maximum quantity to be lifted per month. Adopting the admitted standard of horse-power, viz. 33,000 lbs., raised one foot per minute, and the weight of a cubic foot of water to equal 62½ lbs., or 10 lbs. per gallon, a horse-power will raise 300 gallons, or 5·28 cubic feet of water 10 feet high per minute. The total quantity to be raised per acre per month, viz. 7,260 cubic feet, may thus be raised a height of 10 feet, and discharged in about two hours and ten minutes. Upon this calculation, which Mr. Glynn (a high and practical authority in these matters) has found to be supported in practice, it appears that a steam engine of 10 horse-power will raise and throw off the drainage water due to a district of 1,000 acres of

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fens in each month, in 232 hours, or less than 20 days, working 12 hours a day. The scoop-wheels used for raising the water resemble an undershot water-wheel, but, instead of being moved by the force of the water, they are adapted for forcing the water upward, deriving their motion from the steam engine. The float boards or ladle boards are of wood, and fitted to work within a track or trough of masonry; they are usually about 5 feet long, that is, they are immersed in the water to that extent, the width or horizontal dimension of them being varied, according to the power of the engine and the head of water to be provided for, from 20 inches to 5 feet. The lower end of the wheel track communicates with the main drain, and the higher end with the river, the water of which is excluded by a pair of doors, pointing like the gates of a canal lock, and closed when the engine ceases to work. The wheels are of cast-iron, and fitted in parts. The float boards are attached to the wheel by oak starts, stepped into sockets cast in the periphery of the wheel for that purpose. The wheel is fitted with cast-iron toothed segments, working into a pinion upon the crank shaft of the engine. If the level of water in the delivering drain and in the river does not vary much, one speed for the wheel is sufficient; but if the tide rises to any great extent, it is found desirable to have two speeds of wheel work, one to be used at low water, and the more powerful combination to act against the rising tide. It is usually not necessary to raise the water more than 3 or 4 feet above the surface to be drained, and that only when the river is filled by long-continued rains or floods from the upland. If the main drains be 7½ feet deep, and the floats dip 5 feet below the surface of the water, 1 foot in depth will be left below them to admit the passage of weeds or other matters, and the water will yet be kept 18 inches below the surface of the land. If the wheel dips 5 feet below the drain-water level, and the level of the water in the river is 5 feet above that in the drain, the wheel will be said to have "10 feet head and

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dip," and should be 28 or 30 feet in diameter. For a dip of 5 feet and head of 10 feet, that is, "a head and dip of 15 feet," Mr. Glynn used wheels of 35 feet to 40 feet in diameter. A wheel of 40 feet diameter, and situated on the ten-mile bank near Littleport in the Isle of Ely, is driven by an engine of 80 horse-power. The largest quantity of water discharged by one engine is from Deeping Fen, near Spalding. This fen comprises 25,000 acres, drained by two engines of 80 and 60 horse-power. The 80 horse-power engine works a wheel 28 feet diameter, with float boards 5½ feet by 5 feet, and moving with a mean velocity of 6 feet per second. When the engine has its full dip, the section of the stream is 27½ feet, and the quantity discharged per second is 165 cubic feet, equal to more than 4½ tons. These two engines were erected in 1825, before which time the district had been kept in a half cultivated condition (being sometimes wholly under water) by 44 windmills.

The land now grows excellent wheat, producing (in 1848) from four to six quarters to the acre. In many districts land was purchased by persons who foresaw the consequences of these improvements, which they could sell at from £50 to £70 per acre. This increase in value has arisen not only from the land being cleared from the injurious effects of the water upon it, but from the improved system of cultivation it has enabled the farmers to adopt. The fenlands in Cambridgeshire and great part of the neighbouring counties are formed of a rich black earth, consisting of decomposed vegetable matter, generally from 6 to 10 feet thick, although in some places much thicker, resting upon a bed of blue gault containing clay, lime, and sand. When steam-drainage was first introduced, it was usual to part the land and burn it, then to sow rape-seed, and to feed sheep upon the green crop, after which wheat was sown. The wheat grown upon this land had a long weak straw, easily bent and broken, carrying ears of corn of small size, and having but a weak and uncertain hold

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by its root in the black soil. Latterly, however, chemistry having thrown greater light upon the operations of agriculture, it has been the practice to sink pits at regular distances through the black earth, and to bring up the blue gault, which is spread upon the surface as manure. The straw, by this means taking up an additional quantity of silex, becomes firm, strong, and not so tall as formerly, carrying larger and heavier corn, and the mixture of clay gives a better hold to the root, rendering the crops less liable to be laid by the wind and rain, whilst the produce is most luxuriant and abundant. Mr. Glynn has applied steam-power to the drainage of land in fifteen districts, all in England, and chiefly in the counties of Cambridge, Lincoln, and Norfolk, to the extent of more than 125,000 acres, the engines employed being seventeen in number, of sizes varying from 20 to 80 horses, and having an aggregate power of 870 horses. The same engineer has also drained, by steam-power, the Hammerbrook district, near Hamburg, and designed the works for draining a level near Rotterdam, which have been carried out by the Chevalier Conrad. In British Guiana the steam engine has been made to answer the double purpose of drainage and irrigation. Some of the sugar plantations of Demerara are drained of the superfluous water during the rainy season, and watered during the dry season.

Fresh-water lakes of considerable extent and little depth, are sometimes worthy of being entirely drained for the sake of cultivating the site they occupy. One of the most recent examples of this class of works is the drainage of the Lake of Haarlem in Holland. This lake is situated between Leyden and Amsterdam, and communicates with the Zuyderzee. The bottom of it consists of a rich alluvial deposit well fitted for agriculture. A Dutch engineer, popularly known by the name of "Leeghwater," or "drier up of water," formed a project for draining this lake in 1623, and another proposal for the same object was brought forward at the end of the last century, when steam was

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first employed in draining; similar works having been already executed in the Beilm and Diem. The area of the Lake of Haarlem is equal to 45,230 acres, and its average depth about 14 feet, the cubic contents being equal to 800,000,000 of tons of water. One part of the lake is 13 feet under the level of the tide. The longest side of it is parallel to the sea, and separated from it only by a very narrow strip of land. Observations, continued during a period of 91 years, show that the maximum quantity of rain which falls upon the lake amounts to 36,000,000 tons of water monthly. The Dutch Government having appointed a commission of engineers to report upon the best means of draining the lake, many proposals were submitted and examined, and it was ultimately determined to adopt the plan recommended by Messrs. Gibbs and Dean. These gentlemen employed three engines for the purpose of draining the lake, each being of great power, whereby the total current cost was much less than would be incurred by using a greater number of smaller engines. These three engines are named the "Leeghwater," the "Cruquius," and the "Van Lynden," after three celebrated men of these names, who had interested themselves in the draining of the lake.

Of these three engines the "Leeghwater" was first erected, with suitable houses and pumping machinery. The first step in this work was to construct an earthern dam of a semicircular form, inclosing about 1½ acre of the area of the lake, and adjoining its bank. The space inclosed by this dam was then cleared of water by a small steam engine, and the foundations for the houses and machinery commenced. These foundations consisted first of 1,400 piles, which were driven to the depth of 40 feet into a stratum of hard sand. Upon these piles, and at the depth of 21 feet below the surface of the lake, a strong platform was laid, and upon this a wall, pierced with arches, was constructed, at the distance of 22 ft. from the intended position of the engine-house. Upon this wall a thick floor-

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ing of oak was laid, between the wall and the engine-house. The pumps rest upon the platform, beneath and opposite to the arches, and their heads pass through the floor just described, standing about 3 feet above its level. Into the space left between the engine-house and outer wall, the water raised by the pumps was received and discharged

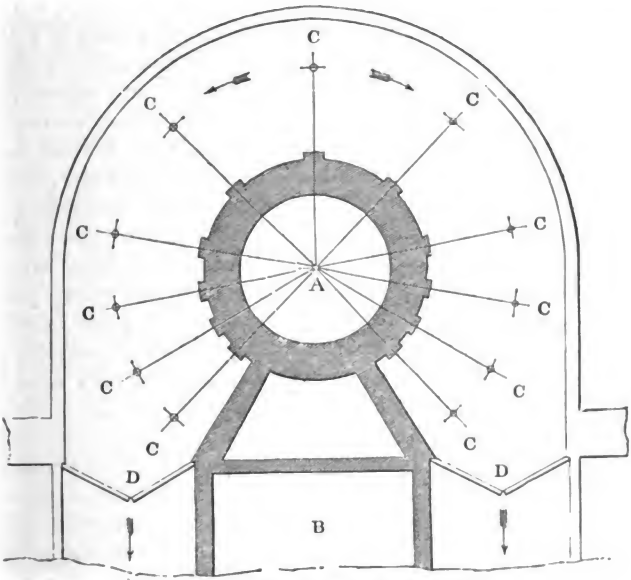

Fig. 43.—Haarlem Pumping Engines.

from it on either side of the boiler-house, through sluice gates, into the canals conducting to the sea sluices. The general arrangement of the engine, boilers, pumps, and sluices will be understood from Fig. 43, in which A represents the engine; B, the boiler-house; C, C, the pumps; and D D, the sluices through which the water was discharged. The engine has two steam cylinders, one within

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the other, united at the bottom, but with a clear space of 1½ in. between them at the top under the cover, which is common to both. The large cylinder is 12 feet and the small one 7 ft. in diameter. The small cylinder is fitted with a piston, and the large cylinder with an annular piston. These pistons are connected by one main piston-rod (of the internal cylinder) 12 inches diameter, and four small rods (of the annular piston) 4½ inches diameter each, with a great cap or cross-head, having a circular body 9 feet 6 inches diameter, and formed to receive the ends of the balance beams of the pumps. The pumps are eleven in number, and each of them 63 inches diameter, with a cast-iron balance beam turning upon a centre in the wall of the engine-house, one end of which is connected with the great cap of the engine, the other to the pump-rod. Each pump-rod is of wrought iron, 3 inches diameter and 16 feet long, with an additional length of 14 feet of patent chain cable attached to the pump piston. The steam and pump pistons have a stroke of 10 feet in length; each pump is calculated to deliver 6·02 tons of water per stroke, or 68·22 tons for the eleven pumps. The quantity actually raised was found to be about 63 tons. The action of the engine is as follows:—The steam being admitted, the piston and great cap are thereby raised, and the pump pistons make their down stroke. At the top of the steam stroke a pause of one or two seconds is made, to enable the valves of the pump pistons to fall out, so that on the down stroke of the steam piston they may take their load of water without shock. In order to sustain the great cap and its dead weight during this interval, an hydraulic apparatus is brought into use, which consists of vertical cylinders, into which water is admitted, forcing upward two plunger poles which sustain the cap, the water being prevented from returning by spherical valves fitted at the lower part of the cylinders. The arrangement of the *two* steam cylinders is adopted in order to bring the load under immediate command, the varying character of which would

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otherwise require occasional alteration of the dead weight to overcome it, which would involve great delays and inconvenience. By the use of the two cylinders, the dead weight raised by the small piston did not usually exceed 85 tons, the extra power required being derived from the pressure of the return steam at the down stroke upon the annular piston. A skilful regulation of the expansion and pressure of steam in the small cylinder thus enables the engine-man to provide for all cases of difference of resistance without the delay of altering the dead weight. Respecting the power of the "Leeghwater," it appeared, from experiments conducted by a sub-committee of the Commission, that the engine would do a duty equal to raising 75,000,000 lbs. one foot high by the consumption of 94 lbs. of good Welsh coal, and exerting a net effective force of 350 horse-power. The lift being 13 feet, the engine worked the eleven pumps simultaneously; the net weight of water lifted being 81·7 tons, and the discharge 63 tons per stroke. When the site of the lake is cultivated, the surface of the water in the drains will be kept at 18 inches below the general level of the bed; but during floods the waters of the upper level of the country will be raised above their usual height, and the lift and head will be increased to 17 feet. To test the power of the engine to meet these cases, the eleven pumps were worked simultaneously, without regard to economy of fuel, and 109 tons net of water were raised, per stroke, to the height of 10 feet. The boilers of the Leeghwater engine are five in number, cylindrical, and each 30 feet long and 6 feet in diameter, with a central fire tube 4 feet in diameter. Under the boilers a return flue passes to the front, and then divides along the sides. Over the boilers, and communicating with all of them, is a steam chamber 42 feet in length and 4 feet 6 inches in diameter, from which a steam-pipe, 2 feet in diameter, conveys the steam to the engine. The consumption of coal is 2½ lbs. of coal per horse-power per hour, when working with a net effect equal to the

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power of 350 horses. The cost of the "Leeghwater" and machinery was £21,000, and of the buildings and contingencies £15,000. It was calculated that the entire cost of the works for draining the lake would be £100,000 less than would have been incurred by adopting the ordinary system of steam engines and hydraulic machinery, and £170,000 less than the expense of applying the system of windmills hitherto prevailing in Dutch drainage. The annual cost of the three methods was thus estimated: by three engines, such as the Leeghwater, £4,500; by windmills, £61,000; and by ordinary steam-engines, £10,000.

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SECTION IV.

Open Drains.—Covered Drains.—Depth of Drains.—Cheap Drains.—Capacity of Drains.—Cost of Drains.—Preliminary Surveys.—Bog-Drains.—Implements.

We have now to consider the form, size, and construction of drains which it will be advisable to adopt according to the circumstances of each case.

The rudest form of drain is that of an open cut or channel in the surface of the ground, for conveying the water which falls in the form of rain, or percolates through the materials intersected, away into some lower position, brook, or other receiver. These open drains are distinguished from the more complete form of underground or covered drains formed by open channels which are afterwards refilled, except at the lower part, along which a channel is preserved by one of several methods of construction. Both of these methods appear to be of great antiquity, having been certainly practised by the Romans, as recorded by Palladius, Pliny, and others.

The arrangement and distances apart of open drains have been usually determined by those of the ridges and furrows. Previous to the introduction of "under-draining," wet and strong lands were prepared for arable culture by being ploughed up into the undulating shape known as "ridge and furrow," the bottom of the furrow forming a rude drain for the water from the adjoining ridges. The wetness of the furrows or "thoroughs," as sometimes called, and of the slips of land adjoining, however, occasioned the perishing of the crops, and led to the adoption

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of shallow drains below the furrows, and commonly kept open with straw or brushwood. This was termed "furrow" or "thorough" draining. In this manner the ordinary width of the lands or ridges in each district indicates generally the distance at which the drains were placed, and the distances now most commonly observed in different districts, and on different soils, have reference to a width of ridge that was, or is, in use in those districts; and it is "a fact worthy of remark, that throughout the country the statements of the number of feet from drain to drain is in almost every instance divisible (when reduced to inches) by eighteen, that being the space of ground in inches moved by a single turn of ordinary ploughing." * The long-established usages of each district may be regarded as indicating the requirements of that district, and the distance from furrow to furrow furnishes a kind of rude index of the comparative tenacity or porosity of the soil, or its capacity for retaining or transmitting water. The tabular statement, p. 73 (as prepared by Mr. Spooner), illustrates the correspondence of the distances between ridges and drains with the character of the soil.

Open drains are applicable only as conductors of surface-water, and for strong tenacious soils. To make them effective in draining from the body of the soil, the depth necessary renders open drains inadvisable; while in loose soils, the inclination of the sides which must be allowed in order to prevent their rapid destruction occupies a most extravagant surface of the land. They are evidently inapplicable to land submitted to the plough, by which they are almost certain to be injured or destroyed, and thus have commonly been restricted to pasture-land, whence they have been named sheep-drains. Even as thus limited, the use of open drains is of very doubtful advisability, inasmuch as they are always much exposed to injury, and to have their banks trodden down and destroyed. Admitting

* Evidence of L. H. Spooner, Esq., of Balmacara House, Loch Alsh.

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TABLE VIII.—Distance of Drains apart.

Width of Land or Ridge.	No of turns of the Plough (18 in. wide) to the land.	Some of the Districts in which the respective widths of Ridge are in common use.	General character of the Soil.	Distance from Drain to Drain, in common use.
ft. in.				
7 6	5	Common in the county of Essex.	Tenacious and uniform clay.	7 ft. 6 in., 15 ft., 21 ft., or every furrow, every other furrow, every third furrow, &c.
16 6	11	Parts of Surrey, Sussex, Kent, Middlesex, &c.	Same as above, fine and silthing clays, with beds of fine sand interspersed.	Drains 1 rod apart.
18 0	12	Parts of Yorkshire, Northumberland, South of Scotland, &c.	Clays, containing coarse sand and grit, interspersed with shale and slate fragments.	Drains 18 ft. or 1 rod (Scotch measure) apart.
21 0	14	Common in the above and the Midland Counties, &c.	Calcareous soils and clays, lighter than the above, with frequent intermixtures of sand and gravel.	Drains 21 feet apart.
24 0	16	Very common in the Midland Counties and the Highlands.	Clays, similar to the above, with rotten sandstone rock and more frequent intermixtures of gravel, &c.	Drains 24 feet apart.
30 0	20	Very generally adopted in the lighter clays throughout the country.	The lighter description of clays and clay gravels.	Drains 30 feet apart.
33 0	22	Parts of Berkshire, Herts, Suffolk, Cambridgeshire &c.	Chalk districts, stone, brush, gravelly, and sandy soils, and the lighter description of lands, usually springy soils.	Drains 33 ft. or 2 rods apart.
36 0	24	Same as above, and very general.	....	Drains 36 ft. or 2 rods (Scotch measure) apart.

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permanent utility as an object in drain-making, it is certain that covered drains should, in nearly all cases, both for arable and pasture districts, be preferred to open ones.

For suburban and road drainage, the reasons for preferring covered to open drains have still greater force than those applicable to land drainage. These reasons are not only economical, but also sanitary. Open drains, presenting a commonly stagnant water surface to the atmosphere, produce an unwholesome evaporation. Decayed vegetable matter accumulates in these drains or ditches, and emits the most offensive effluvia. Near the metropolis there were many large open watercourses, which served to carry away flood waters, when such occur, but at other times the small quantity of water in these channels moved sluggishly over their rugged beds, or lodged in stagnant pools. These ditches sometimes served as outfalls for the drainage of suburban houses, and the effluvium then became at times highly noxious and even fatal. The courses of these ditches were marked by excessive ravages of cholera among the adjoining population.

In carrying out land-drainage, the open roadside ditches are usually found to present most serious obstructions to the work; but if road-drainage were placed, as it should be, in proper subordination to the general system, covered tubular drains for the roads would of themselves effect considerable land-drainage, and in some districts closely intersected with byways and public footpaths, they would sometimes supersede the necessity for any other drainage. On a very stiff clay soil a road drain might, perhaps, not act more than from 12 to 15 feet on either side of it, but in freer soils a single drain would frequently serve a width of from 1 to 2 chains. These road drains, properly constructed, would generally answer as excellent outfalls for the drainage of the land.

The extent of evaporating surface of stagnant moisture with decomposing vegetable and animal matter presented

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by the open ditches on both sides of a mile of road, equals from three-quarters to one acre; that is, by the substitution of covered drains, three-quarters to one acre would be gained as dry road, or cultivable land for each mile of road, besides removing a frequent cause of accidents with horses and vehicles.

Covered drains, being simply intersticial courses formed beneath the surface, may be constructed in a great variety of ways, which may be partly determined by the proximity of the suitable materials. One of the simplest forms, and most generally applicable, consists of a layer of stones in the bed of the drain, which is afterwards filled up with the soil taken out of it in order to deposit the stones, as

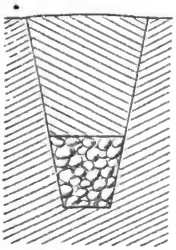

Fig. 44.

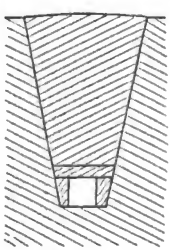

Fig. 45.

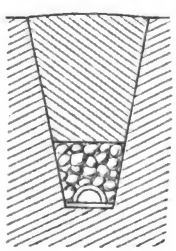

Fig. 46.

shown in Fig44. In these drains there is a liability to become less active, by particles of soil being forced down or brought into the water, and clogging the spaces left for its passage. If stratified stone is cheaply obtainable, the better arrangement represented in Fig. 45 should be adopted, consisting of side stones, and one cover over them, leaving an open space or duct through which the drainage water passes of course more fluently than through the spaces between the stones, as shown in Fig. 44.

A compound drain, composed of a layer of loose stones, and an artificial duct, formed with a flat tile on the bed of the drain, and covered with a semi-cylindrical tile, as shown in Fig. 46, combines the advantages of the two pre-

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ceding drains. This form is commonly denominated the sole-and-tile drain, and may, in most parts of the country, be constructed at less cost than the stone duct shown in Fig. 44. It has also the advantage of greater permanency, being less liable to displacement of the parts. In the drain shown in Fig. 45, the same arrangement of stones over the duct may of course be introduced; but unless the work is very carefully done, and the covering with the flat stones rendered perfect, the loose stones are liable to fall into the duct, and thus destroy its utility.

In clays and tenacious soils, drains such as that shown in Fig. 47, are sometimes formed by cutting the lower part narrower on each side, and thus leaving shoulders, on

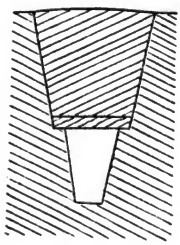

Fig. 47.

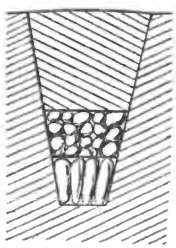

Fig. 48.

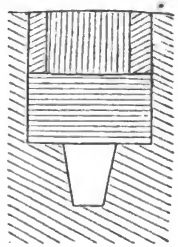

Fig. 49.

which a flat stone being supported, an open space is left below, forming a natural duct or open passage for the water. The permanence of this, the shoulder-drain, is somewhat insecure, as it depends solely upon the shoulders being preserved, and the qualification of the material to resist all damage to the open parts of the drain. Another form of rough stone drain is represented in Fig. 48, for which the larger stones are assorted, and placed in the bed with a layer of small stones upon them. It must be remarked of this, however, as of every rough stone drain, that its permanent action, depending upon the small spaces left between the stones, is very liable, in the course of time, to become much impaired or destroyed by the

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particles of soil and solid matters brought along with the drainage water; and on this account, especially, these drains are far inferior to those constructed with permanent open ducts.

Fig. 49 shows a drain suitable for bog and peaty soils, with which the drain is filled up, leaving an open space below for the passage of the water. The principal objection to this form of construction in peat is, that the effect of dry seasons is to contract the materials, which then get shifted by the superincumbent weight, and sometimes choke the watercourse below. For the purpose of protecting the water-way of drains, turf is occasionally placed over the stones, as shown in Fig. 50, where the water-

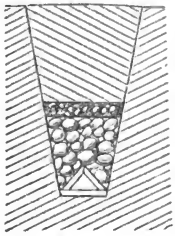

Fig. 50.

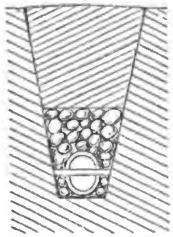

Fig. 51.

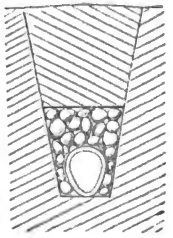

Fig. 52.

course is formed with three flat stones, or otherwise tiles, arranged as the sides of a triangle, and leaving an open duct between them. This duct is covered with a layer of loose stones, by which the stones forming the duct are kept in their places, and upon these stones a layer of turf is placed before filling the drain up with the soil.

Fig. 51 represents a compound drain, having two clear watercourses, and a layer of loose stones for intersticial drainage. The two courses are formed with two semi-cylindrical tiles, and a flat tile or sole between them. In all drains formed with soles and tiles, these are laid so that the joints in one break with those in the other; by which the joints are rendered less liable to be dislocated

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or disturbed than they would be if the joints in the soles and the tiles were laid coincident with each other.

The most complete and undoubtedly permanent form of drain is that which consists of an open channel formed entirely of single pieces of tile-work or piping. These are now generally acknowledged to form the most superior drains; and in nearly all places in this country, their cost will not much exceed that of the imperfect drains formed with loose stones. A drain of this construction is shown in Fig. 52, where the earthen pipe is represented of an egg-shaped section, and a layer of loose stones placed above it. If drains be thus formed, the joints accurately laid, and the whole work carefully done, the drainage will remain in a perfect and unimpaired condition for a very long period.

Drains are liable to injury by vermin, as well as vegetation, the roots of trees, &c., acting in a very injurious manner when their progress is interrupted by underground constructions for drainage. Drains should, therefore, be laid apart from trees, or these cleared away before constructing the drains. The liability to injury by vermin is one feature in which pipe drains are superior to all others constructed of several parts, or depending partly upon the permanent position of the soil in which the drain is formed.

The form of construction being determined, the size of the drains is the next object of consideration. Formerly drains were commonly made of small depth. But deeper ones having been subsequently constructed, and considerable efficiency in the effect obtained, a great desire has arisen for deep drains. In arable districts one imperative condition as to the depth of drains is, that the lower and constructed part of the drain shall be below the action of the plough and other agricultural implements. The structure, depth, and position of the strata are also circumstances that will deserve regard in fixing the depth, as already explained at length in describing the several varieties of sections; and, besides these, another consideration which must be kept in mind is, the rate of fall

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which can be obtained, according to the levels of the surface of the district, to assist the discharge of the contents of the drain. As a general principle, if it were impossible to allow all these circumstances their due weight in arriving at a decision as to the depth of the drains, deep drains are doubtless more safe and likely to be efficient than shallow drains; but while all the facts exist, and may be ascertained, by which the depth should be regulated, it is mere blind prejudice which advocates deep drains in all cases and under all circumstances.

On the depth of drains, the following observations by the late Mr. Smith, of Deanston, are deserving of careful consideration:—"Estimating the thorough drainage of land by the cubic contents of the soil, reckoning from the level of the bottom of the drainage to the surface of the ground, can give no exposition of the agricultural effect, because it has not yet been fully determined by experiment or in practice how far it is beneficial to the growth of plants to remove the free water from the lower regions of the subsoil. One set of experiments over a course of three years has been furnished by Mr. Hope, of Fenton Barns, in East Lothian, from which it appears that the results were in favour of moderate depths of drains; and the practice in the Fens of Lincolnshire shows that the most beneficial distance from the surface for the free water is about 2 feet. In dry seasons, when the water in the level ditches falls below 2 feet from the surface, the crops are found to suffer, and it is customary to dam up the water to that level. Water will rise some inches in soil by capillary or molecular attraction; but in such cases the water never fills the fissures or interstices of the soil to such an extent as to exclude the atmospheric air, but merely attaches itself to the surface of the particles of soil, and of the smaller cells and channels in the soil, where it remains available to the roots of plants, and without any of the bad effects resulting from stagnant free water. Until the great point can be fully and prac-

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tically determined as to the proper distance for retaining a supply of water, the depth to which land should be drained cannot be pronounced. The rule, when ascertained, will probably be found to vary with the nature and condition of the soil. In removing water falling on the surface, it has been found in practice, and which agrees with a great theory, that having the artificial channels at near distances, and not over deep, is most effective in the immediate and complete removal of the free surface water. Distances of from 18 to 24 feet, with depths of from 2 feet to 3 feet have been found, over extensive tracts, and in soils of various texture, to effect complete thorough drainage for agricultural purposes."

As an advocate of deep draining, Mr. Elkington must be named as connected with some very successful experiments in treating land, which astonished the good farmers of the last century, who had been accustomed to pay very little attention to the improvement of their lands in this manner, and had been satisfied to trust the aqueous condition of their broad fields to the hedge-ditch and ridge-furrow. Mr. Elkington, having a farm called Princethorpe, in the parish of Stretton-upon-Dunsmore, county of Warwick, of which the soil was very poor, and so wet that the sheep rotted by hundreds, turned his attention to the best means of draining it. For this reason he began operations in a field of wet clay soil, made nearly a swamp, and in some parts a shaking bog by the springs of water which issued from an adjoining bank of gravel and sand. Mr. Johnstone, who published an account of Mr. Elkington's "system," thus describes his proceedings:—"In order to drain this field, he cut a trench about four or five feet deep a little below the upper side of the bog, or where the wetness began to make its appearance; and after proceeding with it so far in this direction, and at this depth, he found it did not reach the main body of subjacent water, from whence the evil proceeded. On discovering this, Mr. Elkington was at a loss how to proceed. At this time, while

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he was considering what was next to be done, one of his servants accidentally came to the field where the drain was making with an iron crow or bar, which the farmers in that country use in making holes for fixing their sheep-hurdles. Mr. Elkington, having a suspicion that his drain was not deep enough, and a desire to know what kind of strata lay under the bottom of it, took the iron bar from the servant, and after having forced it down about four feet below the bottom of the trench, in pulling it out, to his astonishment, a great quantity of water burst up through the hole he had thus made, and ran down the drain. This at once led him to the knowledge of wetness being often produced by water confined further below the surface of the ground than it was possible for the usual depth of drains to reach, and induced him to think of employing an auger, as a proper instrument in such cases."

These proceedings took place in the year 1764, and it is very evident, from Mr. Johnstone's account of Mr. Elkington's discoveries, and the principles upon which he conducted his draining operations, as distinguished from the methods then in common use, that these methods were adopted without any reference whatever to the leading circumstances which properly regulate the steps to be taken. Thus the three leading points observed by Mr. Elkington, were, "1st, finding out the main spring, or cause of mischief;" "2nd, taking the level of that spring, and ascertaining its subterraneous bearings," a measure never practised by any, till Mr. Elkington discovering the advantage to be derived from it; "and 3rd, making use of the auger to reach or *tap* the spring, when the depth of the drain is not sufficient for that purpose."

The process of tapping is evidently available only when the spring is fed from a higher level, so that the pressure shall suffice to force the water upward through the auger-hole. Another method is sometimes adopted as a substitute for the auger hole or vertical bore, namely, digging a well of depth proportioned to the pressure, and filling this

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well with loose stones, through which the water will rise, and thence pass away along the drain, with the bed of which the well communicates. Similar auger-holes, or wells, may be adopted to effect the precisely opposite object, namely, to make a downward passage of the drainage water from the drains which intersect an upper and clay stratum only, into a more porous bed beneath, in the body of which the water will become dispersed.

The cheapest method of forming open drains in grass land is by turning a furrow-slice over with the plough, and afterwards trimming it with the spade, the lines for the drains being previously marked with poles. The cost of these drains will not exceed one halfpenny per rood of six yards, which is the measure we shall adopt in all cases where the quantity is stated in roods. This mode of operating is inadvisable if the grass be rough and long, so that the plough is apt to become choked, or if swampy places occur. In such cases, it is far better to do all the work with the spade, by which the cost will be increased to 2d. per rood, if the drain be formed about 9 inches wide in the bed, 18 or 20 inches at top, and about 18 inches deep, which is a good size for the minor or sub-drains. Covered drains may be formed in grass-land 6 inches wide in the bed, 18 at top, and about 16 inches deep, at 4d. per rood, by cutting out the upper turf, the whole width across the cut, with the spade, casting out the lower portions subsequently, and then carefully replacing the turf, thus leaving an open space below, equal to the quantity cast out. The permanence of this drain is, however, very insecure; and, if cattle are admitted on the surface, they will certainly tread the turf to the bed of the drain, and thus destroy it. The first cost will, moreover, nearly equal that of a pipe drain, which needs a much narrower cut, and will remain permanently efficient.

In land to be planted with forest trees, open drains are always to be recommended, as covered ones are certain of destruction by the natural tendency of the roots of the

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trees to choke them in their search for moisture during dry seasons. The main drains should be laid along the hollows in the surface, and made at least 3 feet deep, with a flat bed 1 foot wide, and the banks inclined at the rate of 1½ base to 1 perpendicular, except in firm clay soils, in which the banks may be formed much steeper. The minor drains should be for clays not less than 20 inches deep, and light soils 14 inches, with a bed in both cases 9 inches in width, and the inclination of the banks regulated as for the mains. The cost of the former will be about 1½d. per rood, and the latter 3d. per rood. The cost of the mains will be in nearly the same proportion, according to the quantity of soil removed. The best distance at which to lay the minor drains from each other will vary in extreme cases from 5 to 40 yards, according to the levels of the site and character of the soil, the retentive clays requiring the drains closer than the lighter soils.

A general and most important principle as to the capacity of drains of all kinds whatsoever is, that it should exceed rather than be deficient of the dimensions ordinarily required to discharge the quantity of water for which provision is to be made. The principal use of a drain being to attract water towards it through the soil, besides passing the water thus collected away, its dimensions cannot be adequately estimated by simply considering the quantity to be conveyed within any given time. These dimensions should, therefore, be such as to present large surfaces of the soil intersected, and, other circumstances being the same, the efficiency of the drain will be in proportion to the extent of the surfaces, that is, to the depth of the drain. But, on the other hand, if the greater depth of the drain causes it to intersect porous strata overcharged with water from higher land, it will become injurious rather than beneficial, and this evil will be much aggravated if the greater depth be admitted as a reason for the proportionate infrequency of the drains. There can be no doubt that, in tenacious soils, shallow drains laid closely are,

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within certain limits, more useful than deep drains laid wide apart; but, if contiguity can be observed, the deeper they are made the better, in ordinary cases.

Some reasons to guide the depth of drains may be derived from a consideration of the action of the soil upon the water which reaches it, as produced by its mechanical structure. Thus, in light and porous soils, the force of gravity is active in carrying the water to the bottom of the stratum; whereas, in the dense clays and soils, a certain capillary action is exercised upon the water introduced to them, which tends to raise it from the bed, and sustain it in general diffusion throughout the mass. Therefore, while porous soils evince little or no water on the surface, the lower part of the layer will be kept in a state of excessive wetness if it lies upon a clay bed; and, if its thickness be such that the roots of the vegetation reach the wet, the depth of the drains should at least equal that of the porous soil, so that the entire body may be relieved of the water. On soils of this nature, shallow drains are utterly useless, unless they happen to reach an impervious subsoil, and conduct the water into mains of greater depth.

In arable land, the minimum depth for covered drains may be estimated upon the depth to which the plough penetrates, and making such an allowance below this depth as will secure the materials of the drain from disturbance under any circumstances. Mr. Stephens calculates the depth of a furrow-slice with a two-horse plough at 7 inches; but in cross ploughing, 9 inches. If four horses be used, the depth of the furrow will be 12 inches; and if the four-horse plough follow the common one, the depth will be increased to 16 inches. Subsoil ploughing will penetrate 16 inches. below the common furrow of 7 inches. Allowing 3 inches between the lowest disturbed part of the soil and the surface of the materials in the drain, and restricting the effectiveness of the drain to that portion of it which is below the ploughed surface of 7 inches in depth, the minimum depth of drains should be such as

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to allow 19 inches below the furrow-slice, or 26 inches below the surface and above the constructed portion of the drain, and so much more than this if subsoil ploughing be practised. Allowing 6 inches for the depth of the drain occupied by the pipes or tiles, Mr. Stephens estimates 33 inches as the minimum depth of drains in porous subsoils, and 50 inches in clay subsoils, with an additional 6 inches in each case if stones are employed as filling materials in the drain.

The size for the water-passage or duct of a drain should be determined by reference to a variety of circumstances, the combined influence of which may generally be estimated in practice, although not reducible to any very exact rules. Thus, the quantity of rain which falls upon the surface has to be considered, not as an annual or season quantity, but as a maximum per diem. Then, the nature of the soil and the state of the atmosphere, as affecting the ratio of evaporation, require attention. Beyond these considerations, the general level of the district in relation to the surrounding country, by which the tract to be drained may be made the recipient of foreign waters, on the one hand, or kept in a dry condition by the action of gravity, on the other, must be noticed. Again, the structure of the soil affects the quantity of the water which passes through it, and also the rapidity of its passage; and the amount of water to be met with will be modified by the part of the stratum at which the drain is situated. Thus, in porous materials, smaller ducts will suffice in the top of the layer than are required below; and the dimensions must be increased in proportion to the depth of soil above. As an auxiliary fact in enabling us to determine the capacity of the ducts of drains, the frequency of them upon the plan of the district will be greatly influential.

The best evidence on these points, viz. the dimensions and distance of drains, is to be gathered from the records of extended practice. In the weald-clay of Kent, which is commonly of a very tenacious character on the surface, but

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milder below, the body of the water naturally passes downwards until arrested by a more retentive stratum, and therefore, the deeper the drains the more efficiently they will act. In other parts of the weald, the soil is compounded of the supersoil or cultivated earth, and of a strong clay, upon which it lies. The soil admits of percolation, but the tenacious clay beneath it does not, and if this clay be at a considerable depth from the surface, there will be little utility in carrying the drains into it. In these strong clays, not subject to springs, drains 2½ feet deep have been found more efficacious than those made 4 feet deep. In the heavy lands of Norfolk, the drains which answer best are 2½ feet deep, and laid at the distance of 22 feet apart. When they are made deeper, in clay in which flint and chalk boulders are found dispersed about, the labour of taking out the lower bed of 16 or 18 inches is very expensive, costing in that country from 6d. to 8d. per rod of 5½ yards. In the clay lands of Hampshire, the drains made from 30 to 36 inches in depth, and 18 to 24 feet apart, have been found most successful. We can readily understand that, as vegetation requires a certain amount of moisture, it is possible to drain land so effectually that sufficient moisture is not left to fulfil the purposes of cultivation, and the clay soils, which are so reluctant both to receive and to discharge water, will yet suffer a slow and sure deprivation through the agency of deep drains, which will be injurious to the health of vegetation; while drains of less depth would have left the lower part of the stratum in a damp condition, and capable, by the capillary action of the soil itself, of supplying the entire mass with a genial moisture. In Lincolnshire it is a known fact, that if the water in the ditches is reduced to a level below 3 feet in depth from the surface, the grass-land is, in dry summers, most decidedly injured. In the neighbourhood of Folkingham, a tract of clay land was, several years ago, drained with tiles laid 3 feet 6 inches deep, and the surface, which was in broad bands with high ridges, was levelled. After a short period,

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however, the texture of the clay became so solid that the surface-water could not get down to the drains, and it became necessary to alter the method. On the same lands, drains now made 18 or 24 inches deep are found entirely successful. In the neighbourhood of Newcastle-on-Tyne, some clay lands have been drained by drains laid 2½ feet deep and 20 feet apart, with highly satisfactory results. In various parts of Scotland, the subsoils of retentive clay have been more completely drained by drains 2½ feet deep and 18 feet apart, than by 4 feet drains laid 36 feet apart. In the counties of Worcester, Hereford, &c., the best drains in the clays are those laid from 2 to 3 feet in depth; those made 4 and 5 feet deep being found far less effective. Mr. Tebbett, of Mansfield, near Nottingham, states that the best way he has adopted on strong clay lands is putting the drains 14 feet apart and 2 feet deep; while he finds other clays that will draw at 18 to 24 feet apart, and 2 to 3 feet in depth for the drains.

A kind of average scale for the dimensions and distances of drains may be drawn from the experience hitherto had in the draining of land. Classifying the varieties of soils into three divisions, as Compact or Heavy, Medium, and Porous or Light, each of which may be subdivided into several degrees of retentiveness or porosity, the distance of the drains apart may be graduated from 15 to 66 feet, and their depth range from 2 feet 6 inches to 4 feet 6 inches, as in the Table, p. 88, which has been adopted by the General Board of Health in their "Minutes of Information."

The cost of draining is necessarily a theme of deep consideration in the execution of any plan which appears likely to be most successful. The following records state the size and distance of the drains, the nature of the soil, and the total expense per acre.

The first eight of these cases are quoted from Mr. Smith's (of Deanston) pamphlet. They are instances of hard subsoils, with tiles and soles.

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TABLE IX.—The Cost of Land-Drainage per Acre.

The differences in the quality of soils, that lead to differences in the depth and distance of the Drains, are also such as to affect the cost of digging the Drains. An increase of depth necessarily causes an increase of cost, from the mere circumstance of more earth having to be moved. But the same reason that causes Drains to be made closer, namely, the stiffness of the soil, renders them more difficult to dig, and hence increases the price of digging. This will explain how it happens, in the following Table, that the cost per rod is greater, not only as the depth increases, but as the distance of the Drains is less. Of two soils drained at the same depth, the expense of draining a rod will be least in that for which the Drains are furthest apart, which is where the soil is of the freest or least tenacious description.

Description of Soils.		Distance of Drains apart.	Depth of Drains.	Number of Yards of Drains per Acre.	Cost of cutting and filling per Chain.	Cost of cutting and filling per Acre.	Number of Drain Pipes of 12 in. long required per Acre.	Cost of Drain Tiles per Acre, at 30s. per 1000.	Total Cost per Acre.
		ft.	ft. in.		£ s. d.	£ s. d.		£ s. d.	£ s. d.
Compact or Heavy Soils.	Compact tenacious gravelly clay	15	2 6	968	0 1 8	3 13 4	2905	4 7 2	8 0 6
	Stiff adhesive clay .	16½	2 6	880	0 1 7	3 3 4	2640	3 19 2	7 2 6
	Friable clay	18	2 9	807	0 1 6	2 15 1½	2420	3 12 7	6 7 8
	Free soft clay	21	2 9	692	0 1 4	2 2 0	2076	3 2 3	5 4 3
Medium Soils.	Clayey loam	22	3 0	660	0 1 8	2 10 0	1080	2 19 5	5 9 5
	Marly loam	24	3 0	605	0 1 6	2 1 3	1814	2 14 5½	4 15 8
	Gravelly loam	27	3 3	538	0 2 4	2 17 2	1613	2 8 4½	5 5 6½
	Friable loam	30	3 3	484	0 2 0	2 4 0	1452	2 3 6½	4 7 6½
Porous or Light Soils.	Light gravelly loam	33	3 6	440	0 2 10	2 16 8	1320	1 19 7	4 16 3
	Light marly loam ...	36	3 9	403	0 2 8	2 9 4	1209	1 16 3	4 5 7
	Sandy loam	39	4 0	373	0 2 6	1 19 8	1117	1 13 6	3 3 2
	Soft light loam	42	4 0	346	0 2 4	1 16 9	1037	1 11 1½	3 7 10½
	Sandy soil	45	4 0	325	0 2 4	1 14 5	974	1 9 2½	3 3 7½
	Light gravelly sand	49½	4 3	293	0 3 4	2 5 0	880	1 7 4½	3 12 10
	Deep do. do. .	55	4 3	264	0 3 0	1 16 0	792	1 3 9	2 19 9
	Coarse gravelly do...	60	4 6	242	0 4 0	2 4 0	726	1 1 9	3 5 9
	Loose do.	66	4 6	220	0 3 4	1 13 4	660	0 19 9½	2 13 1½

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Nos. 9 to 16 are cited by Mr. Josiah Parkes, in the 6th vol. of the "Journal of the Royal Agricultural Society," the drain-pipes being supposed to be made upon the estate, and costing 6s. per thousand. The remaining cases are also given by Mr. Parkes in the "Gardener's Chronicle," the tiles being made upon the estate, and drawn by the tenants.

TABLE X.—Cost of Drainage.

No.	Soils.	Depth of Drains.	Distance between the Drains.	Cost of Labour per Acre.	Cost of Pipes or Tiles per Acre.	Total Cost per Acre.
		Ft.	Ft.	£ s. d.	£ s. d.	£ s. d.
1.	Clay	...	15	2 11 4	3 0 11½	5 12 3½
2.	Sandy clay	...	18	2 2 10½	2 10 9½	4 13 8
3.	Ditto	...	21	1 16 0	2 3 6½	4 0 3½
4.	Free stony subsoil	...	24	1 12 1	1 18 1½	3 10 2½
5.	Ditto	...	27	1 8 7	1 13 10½	3 2 5½
6.	Porous	...	30	1 5 8	1 10 6	2 16 2
7.	Ditto	...	33	1 3 4	1 7 8½	2 11 0½
8.	Sand or gravel	...	36	1 1 7	1 5 4	2 6 11
9.	Uniform clay	3	33	1 0 0	0 7 11	1 7 11
10.	Ditto	3	33	1 0 0	0 7 11	1 7 11
11.	Ditto	3 to 4	33	1 6 8	0 7 11	1 14 7
12.	Ditto	4½ to 5	40	1 2 0	0 6 6	1 8 6
13.	Clay, with some stones	4	50	1 6 6	0 5 3	1 11 9
14.	Clay. Hard gravelly subsoil	3 to 3½	49½	1 15 6	0 5 4	2 0 10
15.	Ditto	4	49½	1 15 6	0 5 4	2 0 10
16.	Various. Clay, gravel, sand	4	66	1 6 8	0 4 0	1 10 8
17.	Clay. Gravelly subsoil	3½ to 4	33	2 10 0	0 7 11	2 17 11
18.	Heavy clay	4	36	...	...	4 11 7
19.	Various clay	4	36	...	...	3 15 5
20.	Strong clay	4	30 to 33	...	...	4 4 2
21.	Strong land	4	39	...	...	4 15 7
22.	Weak blue clay	4	30	...	...	4 13 11
23.	Whitish stubborn clay	4	36	...	...	4 16 1
24.	Strong clay and gravel	4	33 to 36	...	...	5 3 4
25.	Whitish clay	4	30	...	...	4 4 8

The several items of cost of draining a rectangular field of 20 acres, with drains 3 feet deep, and 22 feet apart, may be averaged thus :—

	£	s.	d.
Main drain, 60 rods, at 8½d. per rod for cutting and filling	2	2	6
Drain-pipes, 990 at 40s. per thousand	1	19	7½
Minor drains, 2261½ rods, at 4½d. per rod	42	8	0
Drain-pipes, 37,320, at 30s. per thousand	55	19	7
	£102	9	8½

Equals £5 2s. 6d. per acre.

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The main drains are supposed to be 3 feet 6 inches deep, 20 inches wide at top, and 4 inches in the bed, with pipes 4 inches in diameter. The minor drains are supposed to be 3 feet deep, 15 inches wide at top, and 3 inches in the bed, with pipes 3 inches in diameter.

The several items of cost of draining a similar rectangular field of similar soil, and prices for cutting and filling in proportion to the sectional area of the drains, the field being, as before, 20 acres in extent, with drains 4½ feet deep, and 45 feet apart, may be estimated thus:—

	£	s.	d.
Main drain, 60 rods, at 1s. 2d. per rod for cutting and filling	3	10	0
Drain-pipes, 990 at 40s. per thousand . . .	1	19	7½
Minor drains, 1,109 rods at 10d. per rod for cutting and filling	46	4	2
Drain pipes, 18,300 at 30s. per thousand . .	27	9	0
	£79	2	9½

Equals £3 19s. 1½d. per acre.

The main drains are supposed to be 5 feet deep, 24 inches wide at top, and 4 inches in the bed, with pipes 4 inches in diameter. The minor drains are supposed to be 4 feet 6 inches deep, 21 inches wide at top, and 3 inches in the bed, with pipes 3 inches in diameter.

Mr. Smith gives estimates for drains constructed with reference to the nature of the soil, which may be arranged as in the Table given on page 91.

Mr. Smith also mentions a district of 10,000 acres of stiff compact clay soil in Scotland, which has been satisfactorily drained with drains 2 feet deep, and laid 20 feet apart.

The principal circumstances which determine the cost of drainage works are—the labour of cutting and filling the drains, the material of which the drain itself is formed, and the outlets for the discharge of water. Of these, the last increases in proportion as the ground is steep and

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TABLE XI.—ESTIMATES FOR DRAINS.

Soils.	Depth of Drain.	Distance of Drains.	Cost per Acre.			
			Cutting and Filling.	Materials.—Tubes, at 20s. per thousand.	Chargeable for Mains, Outfalls, Superintendence, &c.	Total.
	Ft. In.	Ft.	£ s. d.	£ s. d.	£ s. d.	£ s. d.
Alluvial clay	3 0	21	2 1 10	2 2 0	0 18 0	5 1 10
Upland clay or till, full of stones	2 9	21	3 2 9	2 2 0	1 2 0	6 6 9
Compact gravelly drift, with boulder stones	2 9	24	3 4 0	1 16 3½	1 1 0	6 1 3½
Open sand and gravel, with moorish bottom	4 0	40	3 6 0	1 1 9½	1 2 0	5 9 9½
Peat moss, forming its own channel	3 6	18	1 4 5	...	0 6 0	1 10 5

irregular, or unusually flat, and can only be included, in a general estimate, where the surface gently undulates; the material also varies greatly in cost, arising, in the case of tiles, in the supply being near at hand, and equal to the demand, or otherwise; and, in the case of stones, in the distance of carriage.* The following table (XII.) supposes drains opened for stones (as in Fig. 48) and for pipe-tiles; and at depths of 3 feet, 3½ feet, and 4 feet respectively. The table shows the average width of cutting for each size and sort, and the number of lineal yards required to equal a solid yard.

Stones, as used for the filling of drains, are of two kinds, viz. the pebbly or round stones, obtained from the sea-coast, or channels of inland streams, and the fragments produced by breaking up stratified or other rocks, and procured from the quarry. Of these, the former are much superior as the materials for drains, as they preserve the interstitial channels more permanently than the angular scraps from the quarry, the several projections of which are liable both to block up the spaces, and to be broken off by

* See Mr. Spooner's evidence—"Minutes of Information," collected by the General Board of Health, 1852.

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ramming, and thus interfere very mischievously with the passages for the water. As to the size of the stones, the standard commonly prescribed, namely, the "size of a

TABLE XII.—Estimates for Drains.

Description of Drains.	Depth of each Drain.	Width at top.	Width at bottom.	Average Width.	Running yards of Drain to the cubic yard.	Sandy Soils, light Loams, and light Clays; easy digging. At 4d. per cubic yard.		Stiffer Clay and Gravel, quiring some pickwork. At 6d. per cubic yard.		Hard Clay and close Soils, requiring pickwork. At 8d. per cubic yard.	
						Per yard.	Per rod.	Per yard.	Per rod.	Per yard.	Per rod.
	ft. in.	in.	in.	in.		s. d.	s. d.	s. d.	s. d.	s. d.	s. d.
Stone Drains, as in Fig. 48.	4 0	18	8	13	2+*	0 2	0 11	0 3	1 4½	0 4	1 10
	3 6	16	8	12	2½−	0 1⅞	0 9	0 2⅞	1 1¼	0 3½	1 5½
	3 0	12	8	10	3½+	0 1¼	0 6¼	0 1⅞	0 8½	0 2½	1 0½
Pipe Tile Drains.	4 0	18	3	10½	2½+	0 1⅞	0 9	0 2⅞	1 1¼	0 3½	1 5½
	3 6	16	3	9½	3¼	0 1⅜	0 7	0 1⅛	0 10½	0 2⅛	1 2
	3 0	12	3	7½	5⅛	0 0⅞	0 4½	0 1½	0 6¾	0 1¾	0 8¼

goose's egg," is as good as any. At any rate, none should exceed 4 inches in diameter, or be less than 2 inches. In all cases the stones should be assorted according to size, and used separately. Carelessness in this respect often leads to the complete choking of the drain, by the smaller stones filling up the spaces between the larger ones, and forming an impermeable dam across the drain.

Mr. Robertson, of Roxburghshire, who has paid much attention to the construction of rough stone drains, adopts these dimensions for them, viz. 33 inches deep, 7 inches wide at bottom, and 9 inches wide at the height of 15 inches from the bed of the drain, which is the space filled with stones in the manner shown in Fig. 44, p. 75. 15 cubic

* The signs + and − imply a small fraction greater or less than the number stated.

In the prices per rod, the fractional parts are reduced to the farthings nearest to them.

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feet of stones will fill this space in a rood of 6 running yards of such a drain. Mr. Stirling makes his drains of this description, 30 inches deep in the furrows, 5 inches wide in the bed, and 8 inches wide at a height of 15 inches from the bed. A rood of this drain will be filled to a depth of 15 inches by 12·3 cubic feet of stones. Inasmuch as the durability and efficiency of these drains will be nearly in proportion to the space allotted to the stones, it is desirable, if the means will allow such an expense, to make the bed of the drain somewhat wider than here stated. Mr. Stephens prefers 9 inches width of bed, and 18 inches depth of stones, in a drain 36 inches deep.

The cost of Mr. Robertson's drains is thus stated by Mr. Stephens, the drains being laid from 30 to 36 feet apart, and the subsoil favourable to drainage. The averages of these distances gives 70 roods, of 6 yards each, of drains to the imperial acre.

	£	s.	d.
Opening drains 33 in. deep and 7 in. wide at bottom, at 5½d. per rood of 6 yards, for 70 roods	1	12	1
Preparing stones 4 in. diameter, at 4d. per rood	1	3	4
Carriage of stones, at 4½d. per rood	1	6	3½
Unloading carts, and moving screen barrow, at ¾d. per rood	0	4	4½
Filling in earth, at ¼d. per rood	0	1	5½
Extra expense in the main drains	0	10	0
Per acre of 70 roods	4	17	6½
Or per rood of 6 yards	0	1	4¾

In another instance, the expenses were as follows:—

	£	s.	d.
Opening drains 28 in. deep, and 7 in. wide at bottom, at 4d. per rood of 6 yards, for 70 roods	1	3	4
Preparing stones, at 2½d. per rood	0	14	7
Carriage of stones, at 2¾d. per rood	0	16	0½
Unloading carts, and moving screen barrow, at ½d. per rood	0	2	11
Filling in earth, at ¼d. per rood	0	1	5½
Carried forward	2	18	4

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Brought forward	£2	18	4
Extra expense in the main drains . . .	0	10	0
Per acre of 70 roods . . .	3	8	4
Or per rood of 6 yards . . .	0	0	11¾

From these two instances, Mr. Stephens deduces 1s. 1d. as the average cost per rood, the average depth being 30½ inches, and he has calculated Table XIII.

TABLE XIII.—Cost of Mr. Robertson's Drains.

Subsoils to which the Distances are applicable.	Distances between the Drains, in Ft.	Roods of Drains per Acre.	Cost per Acre.
Hard Till	10	242	£13 2 2
	11	220	11 18 4
	12	202	10 18 6
Stiff Clay	13	186	10 1 10
	14	173	9 6 10
Sandy Clay	15	161	8 14 9
	16	151	8 3 10
	17	142	7 14 2
	18	135	7 5 11
	19	127	6 18 0
	20	121	6 11 1
Free and Stony . .	21	115	6 4 10
	22	110	5 19 2
	23	105	5 14 1
	24	101	5 9 3
	25	97	5 4 3
	26	93	5 0 10
	27	90	4 17 1
	28	86	4 13 7
	29	83	4 10 4
Open	30	81	4 7 5
	31	78	4 4 7
	32	76	4 2 0
	33	73	3 19 5
	34	71	3 17 1
	35	68	3 14 11
	36	67	3 13 0
	37	65	3 10 10
Irregular Beds of Gravel or Sand, and irregular open Rocky Strata . .	38	64	3 9 0
	39	63	3 7 2
	40	61	3 5 6

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In using tiles and soles, as shown in Fig. 46, p. 75, the width of the drain in the bed will be determined by the breadth of the soles. For tiles the internal diameter of which is from 3 to 4 inches, the soles are commonly 7 inches in breadth. The length of the tile and sole is of course the same; but this length varies in different localities. The Ainslie machine tiles are 15 inches long when burnt; those made by the Marquis of Tweeddale's machine are 14 inches; but the more common length is 12 inches. Machine-made tiles are in all cases much superior to those made by hand, being more thoroughly compressed, and consequently more dense. Containing *more* clay, they are still *thinner* than hand-made tiles. The 15-inch tiles are less subject to displacement in the drain, and less handling is, of course, wanted to make up any given length. The angular junctions are best formed by semicircular notches in the sides of the tiles into which the ends of the others are fitted. Tiles for main drains are commonly 4 inches wide, and 5 inches high in the clear, and the soles 9 or 10 inches in width, the thickness of both being about $\frac{3}{4}$ inch. The ordinary price of tiles may be taken as about 20s. per thousand, and of the soles, half that of the tiles, or 10s. per thousand. To the cost of the tiles an addition has to be made, averaging from 30s. to 40s. per acre (the drains being 15 feet apart), for the expenses of carriage, loading and unloading, &c., which expenses do not appertain to the common loose stone drains as last described. With the addition of loose stones *over* the tiles, as shown in Fig. 51, the cost will, of course, be considerably enhanced, as compared with that of common loose stone drains, nearly to the extent of the cost of the tiles, and the extra incidental expenses of from 30s. to 40s. per acre, the drains being 15 feet apart. This will, however, form one of the most perfect, durable, and capacious drains that can be applied, and will command attention wherever these objects are sought with minor reference to cost.

Tiles in the form of complete tubes or pipes are, how-

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ever, more perfect instruments of drainage than the separate soles and tiles, being less liable to derangement, and requiring only half the handling. Pipe-tiles, 2 inches in diameter, may be bought at the works at 18s. per thousand, and 15 inches in length; those 1½ inch in diameter at 15s.; and 1 inch in diameter at 10s. per thousand. Mr. Stephens gives the following comparative summary of the cost, per acre, of the three kinds of drain, viz., stones, soles and tiles, and pipe-tiles, the drains being 30 inches deep and 15 feet apart:—

	£	s.	d.
Loose stone drains	8	14	9
Sole and tile drains	7	10	8¾
Pipe-tile drains	5	8	9
Showing a saving by using—			
Soles and tiles instead of stones, of	1	4	0¼
Pipe-tiles instead of stones	3	6	0
Pipe-tiles instead of soles and tiles	2	1	11¼

The late Mr. Mechi stated that his expense of draining an acre of "strong clay land" (in Essex), the drains being 40 feet apart, and average depth 4 feet, amounted to £2 9s. 6d. To this should be added about £1 for the extra incidental expenses which his estimate does not include, and the total cost per acre will be £3 9s. 6d. Without questioning the skill and experience of this gentleman, whose advocacy of thorough draining merited due appreciation, there can be no doubt that it would have been to his greater ultimate advantage to expend a little more money in making the drains more frequent and less in depth.

In comparing these several methods of forming drains, it is perhaps scarcely necessary to state the truth, that first cost does not afford an adequate test of efficiency and permanent economy. To obtain this, subsequent current expenses, and the resulting condition of the soil for agricultural purposes, must also be brought into the account, and will show the benefits to be derived from the use of pipe-tiles still more forcibly.

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The flat stone drains shown in Figs. 45 and 47 are economical forms of construction in some localities, namely, where the required slabs are cheap and abundant. The shoulders, shown in Fig. 47 as being left in the soil, may be in some cases better substituted by clearing the drain out level, and introducing two slabs of stone, meeting at the bottom, and having a stone wedged in between them at the top, the upper portion being filled in with loose stones. If the flat stones at the sides can be obtained 6 or 8 inches broad, and 1½ inches thick, at about 4d. per ton, an acre of land may be drained with drains 32 inches deep below the crowns of the gathered-up ridges, and laid at distances of 15 feet, at a cost of about £2 12s., exclusive of carriage of materials, and the ploughing by which the upper ridges are formed. Constructed as in Fig. 47, if the covering flags can be procured 12 inches wide and 2 inches thick, at the same rate per ton, the acre may be similarly drained for 8s. or 9s. less.

For the draining of bogs, the arrangement represented in Fig. 49 is peculiarly applicable, all the materials being on the spot, as the whole drain is refilled with the peat itself, which is well known to resist the action of water with impunity. Provided the cutting of the drains be done in summer, when the material quickly becomes dried, and sufficient time is allowed between the successive operations of cutting and refilling to effect the required consolidation, no better method is yet devised for effecting this kind of work. The liability of the moss in the bed of the drain to subside in detached parts, and with great irregularity, is certain to destroy any arrangement of tiles, pipes, or other artificial materials.

Another mode of forming drains with the natural materials, called plug-draining, has yet to be mentioned, rather to make our list complete than for any extended applicability of which it is susceptible. Plug drains are practicable only in subsoils of very firm clay entirely free from stones, and which never become thoroughly dry ex-

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cept by evaporation. Their use is further limited to lands the occupation of which is that of permanent pasture. The usual form of open channel being formed in the clay, wooden blocks are introduced, which fit the lower part of the channel to a height of 8 or 10 inches, and are convex or arched on the top. Upon these blocks, or suters, or plugs, the clay is returned and rammed down in a very careful and thorough manner. The plugs are then withdrawn, or drawn forward, for the formation of another length, and leave an open space or duct below for the passage of the water. In Gloucestershire this kind of drain, 2 feet deep, has been executed at from 4d. to 7½d. the rood of 6 yards; but the whole of the operations have to be conducted with extreme care, when the soil is free from frost or much wet, the ramming, moreover, requiring stout labourers, while much of pipe-draining may be performed by women and children; and the finished work is, after all, peculiarly liable, like all other drains formed with natural materials, to the destructive attacks of moles and other underground vermin.

These being the principal forms and constructions of land-drains, some notice of the successive operations to be carried on, and the implements to be employed, is required to complete our account of the draining of districts and lands.

The preliminary survey of the district to be drained having been made, and such indications of the nature of the soil as this survey affords noted, the next desideratum is precise information as to the relative level or altitude, from a fixed datum, of every portion of the surface to be drained. These levels are obtained by the spirit-level in the usual manner, but they should be so complete as will enable us to lay down a plan of the district, with the levels of equal altitude marked upon it. These levels will appear as lines upon the map. Thus the highest point will be represented by a dot. The space around it, at one degree of altitude less, will appear as a continuous line encircling

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the dot. The space which has one degree of altitude less than this is represented by another encircling line around the preceding, and so on, down to the lowest altitude. These encircling lines, called contour lines of equal altitude, will, of course, be more or less irregular, according to the superficial character of the district. They were used in the French Survey, in 1818, having been suggested in an essay read before the French Academy of Sciences so early as 1742, and since adopted for the Irish Survey in the year 1838. A precise idea of these lines may be formed by supposing a block of stone, of an irregular conical form, to be immersed in a vessel of water. If the water be drawn off so as to lower its level equally, say one inch at each successive discharge, the lines on which the water meets the surface of the cone will be the true contour lines of equal altitude. The degree of altitude to be adopted for each contour line will, of course, vary in amount, according to the prominence of the hills and the exactness required, being less in proportion as the district is flat or slightly undulating. From a map thus plotted, combining, as it does, a true plan and infinite sections of the district, any vertical section can at any time be accurately prepared without further reference to the ground, while an immense advantage is obtained in the true indication of all brooks and outcroppings of the substrata of the soil.

The levels being ascertained and recorded, the observations necessary to complete the information upon which the general arrangement of the drains can be determined have next to be made, by means of boring into and examining the structure of the subsoil at various points of the district. The tools, or boring-irons, employed for this purpose, consist principally of the auger, by which cylindrical holes are made in the soil, and their contents brought up to the surface; the punch, with which compact gravel and soft rock are perforated ready for the action of the auger; and the chisel, or jumper, with which, by the aid

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of sledge-hammers, the necessary holes are made in hard rocks which resist the auger and chisel. The auger is from 2 to 4 inches in diameter, and about 15 inches long in the shell. Its form is that of a cylinder, with a longitudinal opening throughout its length, and a sharp cutting edge or *nose* of steel secured to the entering end of it. The form of the punch is that of a pyramid of four sides, from 8 to 12 inches in length, and from 2 to 5 inches square on the base, which is the upper end of the tool when in use. The chisel is a flat tool, with a broad and cutting end, and is made of various sizes, according to the size of hole required. Each of these tools has a screw formed at the upper end, which will fit rods of iron made about 3 feet long and 1 or 1¼ inch square, used to lengthen the apparatus when the hole becomes deeper than the length of the cutting tool. A cross handle of wood, fitted to a tapped socket, that fits upon the tools and rods, is used for the purpose of turning the augers.

When the nature of the subsoil has been ascertained by boring, and the arrangement of main and minor drains determined, the work of forming the drains is commenced by marking the lines upon the surface with poles, and driving stakes to indicate the intended position and direction of the cuttings. A common garden line is then used to mark off the sides of the cuttings according to the width they are intended to have. The ground is then rutted with the spade along the line, and a rut is made at each side of the drain. From 20 to 30 yards are thus lined out at each stage. The different tools to be then employed will vary according to the structure of the subsoil to be removed.

For ordinary soils, such as clays, loams, and small gravel, and the usual combinations of these materials, the common spade, the ditcher's shovel, and foot and hand-picks, are the tools employed. The foot-pick has a cross handle of wood, and a tramp fixed at about 15 inches from the point of the tool, on which the foot of the workman is

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placed to drive it into the soil, and which forms a fulcrum on which stones or lumps of the hard dry clay are raised. The ditcher's shovel resembles a common spade, but is somewhat stronger, and rounded off on each side from the haft, forming a rounded point at the lower end. If the sides of the drain have a tendency to fall in before the work can be completed, they must be sustained by planks and short struts of timber wedged in between them. In order to test the correct dimensions of the drain a gauge is useful, which consists of an upright stem, on which two or three cross-pieces are fitted to move up and down. The stem being graduated, these cross-pieces may be shifted and fixed so as to correspond with the intended limits of the cutting, and applied wherever thought necessary.

The uniformity of the fall of drains is tested with three staves, each consisting of an upright stem, and a cross-piece on the top fixed at right-angles, so that the form of the instrument resembles that of the letter T. Two of these staves are made about 2 feet in height, and the third one equal to 2 feet added to the depth of the drain. The two shorter ones are held perpendicularly, one at each end of the drain, upon the surface of the ground, while the long one is shifted along the bed of the drain, and the prominent or depressed points marked for correction. Besides these staves, a common mason's level, with a plumb line, is a very useful instrument for testing the inclination of the drains. Mr. Denton has designed a still more complete apparatus for this purpose, which he names the A level, from its resemblance to that letter in form, having a cross shifting limb, by which the inclination of one of the legs is adjusted, so that a plumb line from the apex indicates the intended fall, one of the legs having a sliding vernier, and the other having cross hairs for ranging the levels to the end of the drain, with a graduated staff.

In the formation of loose stone drains, after the stones are assorted as to size, and deposited in the drains (for which purposes Mr. Robertson, of Roxburghshire, has in-

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troduced a very complete and portable form of harp or screen, provided with a movable tailboard), they are evenly distributed in the drain with a strong rake, and beaten down with a heavy beater, having a cross-handle for raising it. The best form of shovel for the stones is that known as the frying-pan or lime shovel, having a raised rim around the hinder part of it, and being made of a capacious size.

The cutting of the drains, requiring very exact work, is best performed with tools fitted peculiarly for it. Thus the narrow drain spade produces more perfect work in throwing out the loosened soil, and also trimming the sides of the drain, than the common spade. Pipe drains, being much narrower in the bed than any others, are best finished with small tools designed for the purpose. These are the narrowest drain spades, made only 3½ or 4 inches wide at the mouth, and having a stud or tramp in front for the heel of the workman, to assist in pressing the tool into the soil. Narrow hoes are also useful in removing small stones, &c., from the bed; and for removing any wet and loose earth that may accumulate in it after the cutting of the drain, a scoop formed like a long narrow hoe with raised sides is very effective, being, in use, drawn forward by the workman. The bed of these drains may also be very nicely finished and adjusted with a trowel, formed with the edges parallel, and rounded only near the front.

The objects to be attained in draining implements are strength, combined with lightness, and hardiness; width, sufficient to remove at one cut all the soil required to be taken out of a drain at any one part of it; such a shape of the blade that it shall, when lifted, raise the earth cut, leaving the least possible quantity of broken earth to be removed subsequently. Spades of various widths are needed for cutting the parts of a drain, so that it shall be finished with a regular tapering section with a top width sufficient to enable the drainer to work in it, and a bottom width only equal to receive the material to be deposited.

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Many implements have been introduced of various shapes, and some of them possessing considerable merit; but we have space here to notice only the two principal sorts of drain spades, which have been found in practice superior to all others for working in common soils, and of increased superiority in proportion to the difficulty which the material to be excavated presents to ordinary operations. Of these, the "Markly spade," introduced by Mr. Darby, is admirably formed for removing the lowest 16 or 18 inches of a drain, and has proved its superiority in "shape and

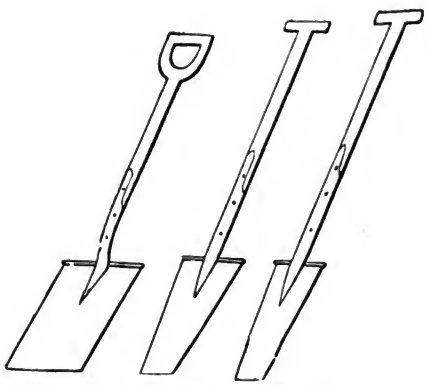

Fig. 53. Fig. 54. Fig. 55.

make" as adopted for cutting through and lifting out a hard gravel or rocky bottom.

Figs. 53, 54, and 55, represent a kind of spade originally used in Kent, and since introduced into Ross-shire and other parts of Scotland, where it has been found to improve the method of cutting the drains, and also to cheapen their formation to a material extent. With such implements as these, a drain 10 to 12 inches wide at top, 3 inches wide at bottom, and 36 to 40 inches deep, may be opened by a single cut from each of these

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sizes.* Drains 40 to 48 inches deep require a double cut in width and depth with the largest of the three spades.

Bog drains are formed with some tools of peculiar form, which may be noticed. Thus the surface turf is cut along the lines of the intended drain with an edging iron of a crescent-like form, and sharpened round its outer edge. For cutting the turf out, a broad-mouthed shovel is used. The moss, being cut into square peats with this shovel, is lifted from the drain with a three-pronged fork made for the purpose, or if footing be found for the workmen, the peats may be neatly cut from the bed, and thrown out with spades fitted with the handle at a large angle to the spade, which may thus be conveniently used in a horizontal position.

In soils where peat is plentiful, this material is sometimes cut or compressed into form, and baked, so as to constitute open ducts when laid together in the drain. Mr. Calderwood, of Ayrshire, introduced, some years ago, a tool fitted to cut peats into a massive semi-cylindrical form by one cut, and without any waste of material, the hollow in one peat fitting the exterior of another. It is said that one man accustomed to the work can cut from 2,000 to 3,000 of these peats in a day. They are afterwards dried in the sun, and stacked till required. Several highly ingenious machines have been invented for forming peat tiles, and also for moulding the pipe tiles of clay of various forms, to secure ready and accurate joints, by which improvements the cost of production has been within late years most materially reduced.

Some part of the work of cutting drains has, at various times, been attempted with ploughs of different forms and construction, fitted, wherever they are applicable, to effect some economy in the cost of labour for the work. Ploughs to facilitate the cutting of drains have been in use for

* Mr. Spooner's evidence—"Minutes of Information," collected by the General Board of Health, 1852.

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many years in districts where alluvial clays prevail, and when used, they have been found to economise the cost of drainage considerably; but owing to the great number of horses (from 8 to 12) required to work them, and the difficulty first experienced by ordinary farm-servants in trying to manage so many horses and such large implements, the use of them has been heretofore much restricted.

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ADDITIONAL SECTIONS ON DRAINAGE OF LANDS.

By D. K. CLARK, M.Inst.C.E.

I.—Rivers.

Rivers, with their tributary brooks and rills, are the natural drains of land surfaces, carrying out to sea the water discharged from the land after evaporation has done its work, either directly off the surface, or that which, after percolating through porous strata to an indefinite depth, is again discharged at the surface as springs. These are the natural outfalls of underground drainage. As the supply in any given district fluctuates, so also does the outflow; but in a vast river system, like that of the Mississippi, the area of drainage is so extensive as to embrace many different conditions of climate and rainfall, and to furnish a discharge which is in a great measure independent of local variations, and is practically uniform. In English rivers, on the contrary, the quantity of flow varies very much with the local rainfall; but as they derive their supply also from springs, they continue to flow in dry weather.

The disposal of the rainfall varies according to conditions, as already discussed, page 5, &c. The proportion of the rainfall that flows into and supplies the rivers appears generally to vary from one-third to one-fourth, although in mountainous districts, having a large rainfall and a short distance from the sea, the proportion which returns to the sea must be much greater. According to the results of Mr. Bateman's observations for seven years in the Loch Katrine district, a rainfall of 87½ inches at the head of the

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loch, over a drainage basin of 71½ square miles, yielded an outflow of 81·70 inches. It is certain that the effect of under-draining has been in many cases to diminish the flow of rivers in dry weather, and to augment it in wet weather: so increasing both the droughts and the floods.

The general subject of the treatment of rivers extends beyond the mere question of drainage, and readers are referred to the chapter on rivers in the rudimentary treatise on "Civil Engineering," 1881.

II.—Lands for Drainage.

The lands requiring to be drained may be divided generally into two classes:—first, the surcharged free or porous soils; and secondly, the absorbent retentive soils, known as impervious clays. The free soils are subject to natural though slow drainage before they are artificially drained, by percolation from a higher to a lower level, the discharge from these being the springs which burst from the lower outcrops to feed the natural channels. The clay soils in their undrained state only release the water they absorb by evaporation, the little water that is not evaporated oozing into the free soils and the porous wells with which they are in contact.

The total extent of wet lands drained, or capable of improvement by draining, in Great Britain is, according to Mr. Bailey Denton, estimated at 22,800,000 acres, out of the total area of 56,352,000 acres. The extent of land permanently drained did not, in 1861, reach 1,500.000 acres, so that there remained undrained about 21,300,000 acres. The extent of the free soils drained or requiring draining is about 12,000,000 acres out of the 22 800,000, leaving about 10,800,000 acres of clay land. These quantities indicate the magnitude of the field to which underdrainage is gradually extending itself, and for which provision must be made in the main arteries and outfalls.

The free soils are further distinguished from the clays, by the rules practically recognised in the operations of

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under-drainage. The free soils are susceptible of drainage by deep drains at wide and irregular distances; the number of drains being governed by the depth at which they are constructed, and their position by the form of the ground and special condition of subsoil, test-holes being the best index to successful and economical drainage. For the clays, on the contrary, the whole soil must be uniformly drained, and be thoroughly aërated by frequent drains, to overcome as much as possible its retentive properties. Test-holes, it is found, in many kinds of clays are no criterion of the effect of under-drains, and they cannot be used as guides, as they are in free soils. The mere "gridiron" of drains, represented by the lines on a map of a clay soil, are fitting to the soil. But for wet free soils, the extent of which in Great Britain is about equal to that of the clays, scientific skill is required for the proper disposition of the drains. It is not required in such soils to multiply drains to overcome excessive retentiveness, but it is required to reduce the water-level through percolative matter, and to let off, carefully and gradually, the rain which falls upon the surface and the water which gravitates through adjacent land into such soils. Not to extract it too freely, but to remove the evil of stagnation, and to discharge the water into the rivers with as little disturbance to the arterial system as possible. Not to gridiron each field as a separate work, but to regard each valley or area of saturated free soil as subject to a system of drainage capable both of overcoming stagnation and of increasing the perennial water supply. It is not possible to remove surplus water from clays too quickly, but it is quite possible to remove it too rapidly from free soils. In fact, the more gradual the action of drainage, so long as the water is kept moving, the better for this kind of land, and the less derangement of the arterial system would be the consequence. "When once drained," says Mr. Bailey Denton, "the surcharged free soils partake of the same character as those which are naturally dry, and they are equally capable of absorption and percolation, the only difference being the depth of the

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subterranean water-level, which, in the case of the higher chalk and the sand formations, sinks beyond the reach of evaporation, but which in the case of drained lands, though lowered by the operation of draining, remains within reach. The clays, on the contrary, though rendered capable of rapid filtration by under-drainage, still possess their peculiar powers of retention and expansion, which limit their capabilities of absorption, and cause them to resist, more or less, according to the state of the surface, the admission of falling rain as rapidly as the free soils. The free soils which suffer from wetness should be understood to include the drifted and alluvial beds, which cover the impervious older strata, as well as the outcrop of the water-bearing strata at their lower levels. Percolation and evaporation are ever more or less at work on these soils, and the breadth of injurious wetness is determined by the extent of land, the under-water of which is tributary to, and shows itself at, the saturated outcrop, and the inclination of the impervious base upon which the saturated soil rests."

Wet free soils include gravels, sands, peats, loams, and every kind of mixed earth. Clays of various density are frequently found mixed with the drifted free soils. The clays are called marls, loams, and gaults; and whenever any soils exist with a proportion of one-tenth of argillaceous matter in their constitution, they are to be treated as clays.

The composition of free and clay soils on the Hinxworth estate, at the bottom of the northern escarpment of the London basin, was determined by Professor Way as follows :—

Free or mixed soil :—	Per cent.
Moisture and organic matter	3·27
Sands and clays	24·37
Silica soluble in acids	1·23
Oxide of iron	1·14
Phosphate of lime	·92
Sulphate of lime	·76
Carbonate of lime	68·31
	100·00

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	Per cent.
Gault clay :—	
Moisture and organic matter	5·01
Sands	·66
Clay	63·26
Carbonate of lime	31·07
	100·00

III.—Arterial Drainage and Under-Drainage.

The drainage of land is distinguished as superficial or arterial drainage, as it is called, by the medium of streams and rivers; and under-drainage, or drainage below the surface by means of pipes or other means of communication.

Upwards of fifty years ago, in 1834, Mr. James Simpson drew attention to the fact that insufficient attention had been paid, in the majority of instances, to the question of outfall, as single farms, and even single fields, could be operated upon at the pleasure of the owners and occupiers. "The experience of recent wet seasons," he says, "has proved that large tracts of upland have been drained, to the detriment of lower levels. It has also become evident that arterial drainage in many agricultural districts demands more attention than it has hitherto received, and that the trunk lines, or the principal watercourses, and the fields contiguous to them, will be liable to be as constantly flooded in wet seasons as they have been during the last two years (1852 and 1853), to the great injury of the pasturage, and the serious detriment of all farming operations in low lands, if measures for the arterial drainage and for the improvement of the trunk lines, or principal watercourses, continue to be disregarded. The obstruction of brooks and streams, arising from milldams, and from artificial as well as natural weirs, applied to exclusive uses, and to the irrigation of particular and comparatively unimportant properties, are too frequently maintained to the disadvantage and injury of large tracts of land." *

* See "Minutes of Proceedings," Institution of Civil Engineers, vol. xiii., page 200.

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There was scarcely a district in this country but where either the lands could not be drained at all, or they were injuriously affected by the drainage of the lands above them. In the first case, for instance, disabled districts were situated between the sources of streams on the one part and the natural outfall on the other part, so that the owner of an estate so situated could not legally straighten or deepen the stream or river running through the estate, and thereby drain his land, because he would by so doing inundate his neighbours' land lower down the stream. In many cases a single person who was unwilling to drain his property might prevent any improvements by adjoining owners, however much they might desire them.

Subterranean or pipe-drainage has generally been adopted as the first step in the improvement of land. So far as it has been applied, it has largely augmented the quantity of water flowing in field-drains and ditches, which are better cleared out, and in rivers, brooks, and streams. The water in consequence is discharged in a shorter time than before, giving rise more frequently to floods, the courses of brooks and streams being, in numerous instances, insufficient to convey away the large volumes of water which are suddenly discharged into them. At other times the rivers and streams contain less water than before sub-drainage was effected: not even, in many cases, sufficient to supply the ordinary demands of the country or of the towns dependent upon them. It may be imagined that, as the water falling upon the surface of undrained land can now be run off, in the course of a few days, to the arterial drains and outfalls, instead of slowly trickling through the soil, how imperative it is that provision should be made to carry off water in the most direct and efficient manner, and that ample allowance should be made for much larger flows of water.

In brief, the points which immediately concern the engineer in settling a scheme of arterial drainage and outfall, are the straightening and deepening of internal as

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well as tidal rivers, in order to provide uniform inclinations from the sources towards the outfalls. The gradients should be adopted with regard to the nature of the soil through which the rivers flow, to obviate the scouring action of the water on the banks and the bottoms of the streams. It is also necessary in many cases to reconstruct bridges and culverts of sufficient capacity to meet the augmented flow, and to provide reservoirs and other works for storing the field drainage, so as to maintain a constant minimum supply to the channels of rivers, and for irrigation of adjoining lands, and supplying cattle in dry seasons, for small water-wheels, and for the supply of towns and villages which, in many cases, may otherwise be altogether deprived of supplies by any complete system of drainage.

The formation of shallow rather than deep surface drains should be encouraged in nearly all kinds of soils. The system of banks on the sides of shallow drains may be advantageous in localities where sudden floods occasionally occur, so as to minimise excavation and waste of land. These banks and the spaces between them and the rivers are available for pasturage.

The outfalls of rivers, of course, are differently affected by draining. The river Thames, having a low rate of fall, remains longer in flood than it did when the lands were but partially drained; for, when the lands had been thoroughly drained and became saturated by continuous rain, the drains would pass off water more freely, and thus augment the volume of the river. The same effect may be produced in every river having, like the Thames, a low rate of fall, and it is only in rivers of that class that attention to the outfall is required. Taking, for contrast, the case of the river Tweed, which has a rapid fall, and passes through a district which in general has been thoroughly drained, the floods are not so high as they were fifty years ago, although they both rise and fall more rapidly than they did formerly. These are the important results of the general introduction of under-drainage, noticeable in the case of

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this river :—the water now percolating to the drains, the surface soil is not washed away from the land into the river, and, consequently, the river, during floods, is less charged with mud, and hence there is less deposit carried to the river's mouth to form bars and impediments to shipping.

Yet it must be acknowledged that subterranean drainage often has the effect of increasing the magnitude of floods, particularly in the case of prolonged rainfall. Many bridges which had stood for ages without injury have been washed away by floods, and it is an ascertained fact that in nearly all districts, from some cause or other, the floods have greatly increased in volume, and the flow in dry weather has as perceptibly diminished. Water-millers have concurred in opinion that the extension of sub-drainage has had the effect of increasing the severity both of the floods and of the droughts.

It is stated by Mr. Bailey Denton, as the result of observations reaching over many years, that the length of the discharging period of under-drains has been found to depend, not so much on the duration and the quantity falling during the immediate period of discharge, as on the wetness of the preceding seasons. If the preceding winter has been subject to an ordinary rainfall, and the summer has been dry, as in 1859, with active evaporation, the discharge of the main drains will commence late in the autumn ; whereas if a wet winter is succeeded by a wet summer, like that of 1860, it is possible that the under-drains may not cease running during the whole year. Under ordinary conditions, the under-drains of the free soils will begin to discharge in the month of October, or the beginning of November, and those of the clays in the end of November, or the beginning of December. The difference of time is no doubt due to the absorbent qualities of clays, by which they seize, and to their retentive powers, by which they hold, the first water which reaches their inner masses, whereas the free soils, not possessing the retentive property in anything like the same degree, allow any excess

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to pass away gradually, after the subterranean level has been regained. In a majority of instances, in which free soil requires under-draining, it is found that surrounding or adjoining lands of a higher level and of the same stratum have a great influence upon the extent and continuance of wetness, and this fact regulates, more or less, the period of discharge. The under-water percolating the soil in a diffused or general manner, from a higher to a lower level, —designated by Mr. Denton the "water of pressure"— has much more effect on the under-drainage of land than is generally admitted, for it has been considered a matter of supererogation to look beyond the four sides of the field to be drained and to inquire into the real cause of its wetness, which is often beyond the field itself.*

IV.—Mr. Bailey Denton's Experiments with Under-drainage at Hinxworth.

Mr. Bailey Denton made a series of experiments on Hinxworth estate, near Watford, in 1856-57, to ascertain the relative fall of rain on the surface and the discharge of water from the under-drains, over an area of several hundred acres of cultivated ground, in a central position in Great Britain. The experiments did not extend to the entire estate of 800 acres, but only to certain fields containing about 100 acres, in equal proportions of the two descriptions of soil—the free soils and the clays. They are typical of the land requiring systematic under-draining. The estate lies at the bottom of the northern escarpment of the London basin, and covers a portion of the lowest bed of the chalk, the outcrop of the greensand, and a portion of the gault of the greensand formation. In several parts a superficial deposit of drifted, mixed, or free soil overlies the older beds. The layer of greensand is very thin, and it was in draining through this bed that the coprolites, which have since been raised in large quantities,

* "Minutes of Proceedings, Institution of Civil Engineers," vol. xxi., page 52.

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were first found. The gault was remarkably stiff and tenacious, though impregnated with lime from its proximity to the chalk—a special condition, which allowed the water, contrary to general experience, to preserve a level in the test-holes agreeing with that in the subsoil. Analyses of the free soil and the clay have already been given at pages 109, 110.

Although the whole of the estate was drained by one connected system of works, the mode of draining each description of soil was necessarily as different as the soils themselves. The free soils were drained by occasional wide parallel drains from 4 feet to 8 feet deep, at a cost varying from £1 10s. to £3 10s. per acre, and the number of drains was reduced to a minimum, on the principle that any excess of work beyond what was sufficient to remove injurious wetness would be a waste of outlay. The gault clay, on the contrary, was drained uniformly by a series of parallel drains, 25 feet and 27 feet apart, 4 feet deep, at a cost varying from £5 10s. to £6 10s. per acre, and the number of drains was increased to a maximum consistent with economy. The object was twofold—to remove excess of wetness, and to promote the aëration and disintegration of the soil, so as to counteract as much as possible its retentive properties.

The two systems of drainage, applicable to the two characteristic descriptions of soil, are represented in Fig. 56, which is the map of an estate in the neighbourhood of Rugby. The number and position of the drains marks the different soils.

The experiments at Hinxworth extended from the 1st October, 1856, to the 31st May, 1857.

The rainfall in	1853	amounted to	24½	inches.
,,	1854	,,	19	,,
,,	1855	,,	24·6	,,
,,	1856	,,	23	,,
,,	1857	,,	21½	,,

As the average rainfall in the district is 24 inches, it appears that there had not been any extraordinary fall of

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rain preceding the experiments. The greatest fall in 24 hours was ·542 inch, which is not excessive; and whilst

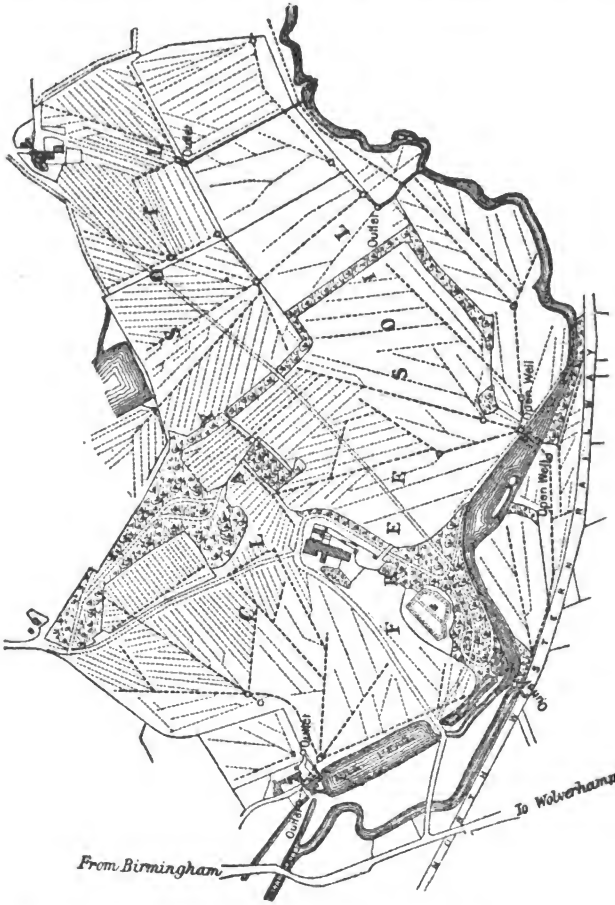

Fig. 56.—Drainage of an Estate near Rugby.

the average fall for the eight months of experiments is 13 inches, the actual fall was 10 045 inches.

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Before the free soils were under-drained, the subterranean water-level gradually rose as it was replenished by the rains of autumn and winter, until, in February, the soil became fully saturated to the surface, which was chilled by evaporation—a condition of things which lasted till the middle of March. In April, slow percolation downwards, and rapid evaporation upwards, exceeded the rainfall, and lowered the water-bed, so allowing vegetation, weakened by wet and cold, to struggle into growth. It was only when the free soils were full to the surface that the land-springs broke from the slopes, rising higher and higher as replenishment advanced. At that time, also, heavy and successive rains flowed over the surface to the outfalls, and augmented the freshets which filled the valleys.

Before the clays were under-drained, they absorbed and retained the autumn rains until, when they were completely saturated, the excess water flowed off by the land furrows or by the slacks and hollows off the natural surface; or it remained on the ground until it was dissipated by evaporation.

But the under-draining changed all this. In the free soils, under-drained, no water can run from the under-drains until the water-bed has been raised by the descending rains to the level of the drains. But the lowest drains begin to run fast; and as soon as the water-bed of the whole area drained, forming an inclined plane, has risen by degrees to the height of every drain, and not till this takes place, the whole system is at work. A portion of the infiltrated water is claimed by the space in the subsoil intermediate between the level of the drains and the depth to which the water-bed may have sunk after the drains have ceased running in the spring. The quantity discharged by the drains, therefore, does not represent the whole of the infiltrated water. This includes, first, the water discharged by the drains; secondly, the water which gravitates to the outcrop springs; and, thirdly, the moisture which returns upwards from the subsoil beneath the drains, by

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attraction into the soil above them, to be dispersed by evaporation at the surface. In cases where the surcharged lands approach the lowest outcrop, or lip of the stratum or bed, the drains partake of the nature of perennial springs, and they continue to discharge the overflow of the subjacent water-bed during all the year.

That the system of drains adopted was effective was proved by the test-holes dug midway between the drains. The quantity of water discharged by the under-drains from the free soil was a large proportion of the rain which fell during the period of discharge. The rain which fell on the surface during the eight months was 10·045 inches, or 227,220 gallons per acre; whilst a little over 7 inches, or 160,550 gallons, which is more than two-thirds of the rainfall, was discharged. But, during the remaining four months of the year, the discharge was very trifling, whilst 11½ inches of rain, or 260,153 gallons per acre, fell during the same period, making the average discharge for the year less than one-third of the total rainfall. For free and mixed soils, taken together, the discharge is estimated at one-fourth of the rainfall. The monthly rainfall and discharge from the free and mixed soils, reduced to average daily quantities per acre, were as follows:—

Free Soil.	Rainfall per acre. Gallons.	Discharge per acre. Gallons.
October	1200	211
November	1229	484
December	901	678
January	1702	1337
February	155	744
March	578	262
April	1085	293
May	547	148

Turning now to the under-draining in clay soil, it has been stated that the discharge from the free soils preceded that of the clays by a considerable time. These did not discharge until the end of November. The discharge began slightly on the 24th, though the water had not risen to the level of the drains. By that time the 3¼ inches of rain

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which had fallen in October and November had just sufficed to fill the inner pores of the soil and its more minute interstices. On January 10, when a fall of ·542 inch, or 12,261 gallons per acre took place, the soil was filled to its capability of retention. From a flow of 125 gallons per acre on the 9th, the discharge was increased to 5,150 gallons on the 10th. In December, when it was observed that the soil was not full to the head of the drains, the fall of ·452 inch of rain on the 13th, or 10,225 gallons per acre, did not affect the discharge very much, being 160 gallons per acre on the 12th, and 975 gallons on the 13th. The monthly rainfall and discharge from the clays at Hinxworth, reduced to an average daily quantity per acre, were as follows :—

Clay.	Rainfall per acre. Gallons.	Discharge per acre. Gallons.
October	1200	nil.
November	1229	11
December	901	188
January	1702	1026
February	155	323
March	598	107
April	1085	206
May	547	110

The total quantity of water discharged annually by the clays is small compared with that discharged by the free soils. It was only 59,931 gallons per acre, or about 9¼ inches.

V.—The Reclamation of Hainault Forest, by Mr. R. B. Grantham.

The reclamation of Hainault Forest, formerly a royal forest, in the county of Essex, between Ilford and Romford, is an instructive example of the combined application of arterial and under-drainage. It was laid out by and executed under the direction of Mr. R. B. Grantham, in 1859, as shown in Fig. 57.*

* See Mr. R. B. Grantham's paper "On Arterial Drainage and Outfalls," in the "Proceedings of the Institution of Civil Engineers," vol. xix., page 53, from which the above particulars are derived.

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The allotment made to the Crown contains about two

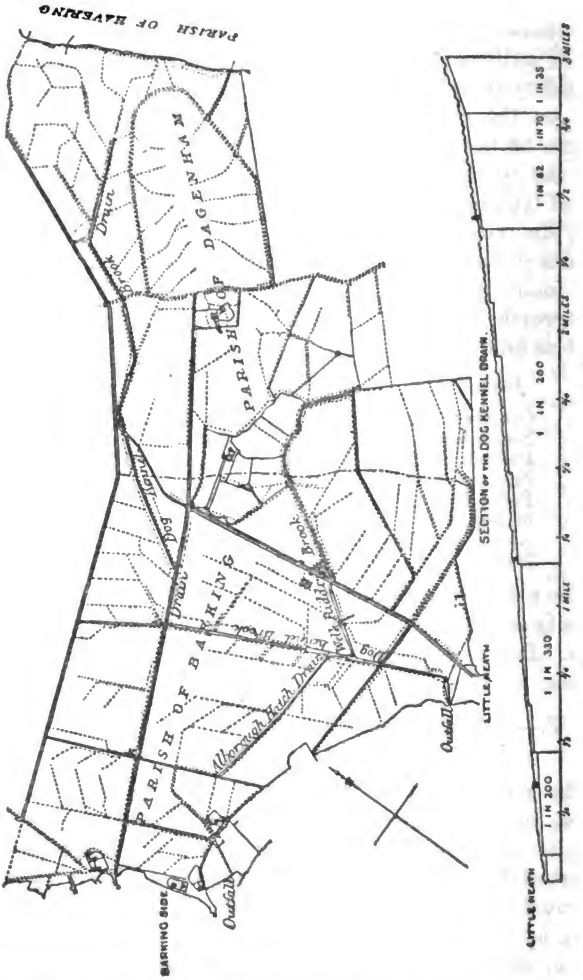

Fig. 57.—Drainage of Hainault Forest.

thousand acres. It was disafforested in the year 1853, and

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all the timber, consisting of oak and hornbeam pollards, was cleared off in the three following years. The land in its original state was covered with a thick growth of underwood, as well as of timber, coarse grass, rushes, and weeds, and the greater part of it was a mere swamp. The formation of the ground consists of a level plain, part of it known as Fairlop Plain, lying at the foot of a ridge of land sloping toward the south. Another ridge projects into it from the east, and at the foot of the ridges are valleys, which bring down the water from beyond the limits of the Crown allotment. The soil on the northern and south-eastern sides is generally a strong brown clay; the remainder of the allotment is mixed clay and gravel.

The first operation in the reclamation was the making of roads and arterial drains. Some of the roads are parallel to arterial drains, as shown in Fig. 57. Material was thus afforded for the formation of the roads, and much severance of land was obviated.

Of the three principal valleys, the first is the Dog Kennel Brook, which extends from the southern boundary of the allotment at Little Heath, and runs nearly due north to the northern boundary, where it receives the drainage of the ridge upon which Chigwell Row stands, and, branching off at the second road towards the north-east, receives the drainage of that part of the same ridge.

Out of the Dog Kennel Brook, about half a mile from its outlet at Little Heath, the Well-Ridden Brook branches off towards the north-east, and receives the drainage of the land for some distance beyond the boundary of the allotment. A little above where the last brook branches off from the Dog Kennel Brook, and on the opposite side, is a small drain, the Aldborough Hatch drain, which receives the drainage of the west and north-west parts of the allotment, and the lands north of it. A small portion of land on the west side is drained by a separate outfall. This is the only portion of the water which is not discharged by the Dog Kennel Brook outlet.

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In each of these valleys, straight and regular open drains have been formed, proportioned to the quantity of water it was calculated they would carry off. Into these open drains all the mains of the pipe-drainage, which has been executed over an area of about two thousand acres, have been carried; as well as the surface-water of the allotment and land adjoining. The water which formerly passed through these valleys can scarcely be said to have been carried off by streams, as there was little or no indication of any ditch or track by which it could be discharged; but it found its way over a great part of the land, where it lay for weeks, destructive of vegetation and of health, till it was for the most part carried off by evaporation. It was frequently midsummer before the land was sufficiently dry to walk upon; consequently little produce was grown, and the quality was almost worthless.

The length of the Dog Kennel open drain in a line from the south to the north-east is about 3½ miles; the area drained by it is upwards of 3,000 acres. The Well-Ridden drain, to the north-east, is 1¼ miles in length, and receives the drainage of 670 acres. The West drain is 1¼ miles in length, and it drains 452 acres.

It was expected that the water from the high ground surrounding the allotment, and from the large quantity of underground pipes in the allotment, equal to 615 miles in length, would be discharged in large quantities and in very short periods. The following dimensions and slopes accordingly were given to the drains. The bottom of the Dog Kennel drain, at its outlet, was made 6 feet wide, and from 4 feet to 5 feet deep: the bottom width diminishing gradually to 2 feet at the upper end. The inclinations of the bottom are shown on the section accompanying the plan, Fig. 57. The natural fall of the valley, at the surface of the land, to the second road, is 1 in 171 and 1 in 125 for some distance above the road. This fall would have been too great under the circumstances before stated, and the velocity of the water would have been such as to

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destroy the sides and bottoms of the drains. Overfalls built of brick were therefore put in the drain, as indicated in the plan and shown in the section. By these means the gradients were reduced to 1 in 330 in the lower part, and 1 in 200 in the upper part The overfalls vary from 10 feet to 3 feet in width of opening, and rise from 3 feet to 5 feet; and they were so constructed, by inserting boards into grooves, as to be capable of being made into dams for storing water in dry seasons for watering cattle or other purposes, and for irrigating the land on both sides. The Well-Ridden drain was the only other drain that was treated in this manner. Its gradient was reduced from 1 in 147 to 1 in 200, by two overfalls.

The dotted lines on the map, Fig. 57, show the pipe-drains, the smaller pipes leading into the larger or main pipes, which discharge into the open drains at the points shown. The minor drains accurately describe the contour profile of the land, their direction being that of the greatest fall.

At one of the farm buildings a tank was constructed to supply the premises with water, and there is a feeder leading to it, branching out of the Dog Kennel drain, where a dam is placed to regulate the quantity of water.

The system adopted in thoroughly draining this large district was to have as few open drains as possible; and mains with large pipes were extensively used, considerably increasing of course the first cost. But the area of land thereby gained for profitable cultivation was increased in proportion, and the labour of tillage largely reduced. Agriculturists neglect the mouths of under drains, if numerous, and consequently it is economy to have as few outlets as possible. The result of the arterial drainage in connection with the underground drainage has been that all the rainfall is carried off with the greatest facility. In no case have any of the open drains overflowed, the water having all been confined within the banks. The forest, formerly useless, has become a valuable farm.

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VI.—Rainfall.

The air is the great conductor of moisture from the sea and other sources to the springs and streamlets which feed the rivers. Air is never free from aqueous vapour. On the coldest day it holds moisture, and it will even carry it off from snow or ice; and, popularly speaking, the hotter it is the more capable it is of absorbing moisture and holding it in suspension. The fact is, that if two or more gases or vapours, not having any power of chemical action one upon another, be introduced into the same space, each gas will, after a certain interval, be diffused equally throughout the whole of the space, and will occupy the space exactly as if no other gas were present. The gases thus become intimately mixed. If a vessel be filled with dry air, and a sufficient quantity of water be introduced into the vessel, the water is evaporated, and the vapour occupies the vessel just as if the vessel had been empty and had previously contained a vacuum. Evaporation proceeds until the vapour becomes saturated; that is to say, until the pressure and density of the vapour arrive at the maximum due to the temperature of the mixture. Air is said to be saturated with moisture when the moisture or vapour it contains is itself in the condition of saturation, or of maximum density due to the temperature of the air.

The quantity of moisture present in the air varies considerably in different countries and at different seasons. In England, the average proportion is said to be about 1½ per cent. The annual evaporation from the surface of water at Lea Bridge and Plaistow was proved to be about 21 inches per year, of which about 4 inches were taken up in January to March, 8 inches in April to May, 7 inches in June to September, and 2 inches in October to December. Dr. John Evans states that at Dijon, in France, about 26 inches was evaporated in the year; and the results of extended observation in Denmark show about 28 inches

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from water, 30 inches from short grass, and 44 inches from long grass. At Madras there is an annual evaporation of about 90 inches. It is thought that in nearly all parts of the globe the evaporation from a free water-surface is on an average about equal to the rainfall. The result of Mr. Charnock's experiments at Holmfield, already stated, p. 11, &c., tends to substantiate this general deduction, even to surpass it in terms. The quantity of rain which fell on the surface, and the quantity of water evaporated from a soil maintained in a state of saturation, are abstracted as follows:—

	Rainfall. inches.	Evaporation from saturated soil. inches.
1842	26·11	30·02
1843	24·49	31·19
1844	19·00	37·85
1845	28·18	31·09
1846	25·24	33·68
Averages .	24·60	32·68

showing that the evaporation from a saturated soil may even exceed the rainfall.

In falling from the clouds, rain increases in quantity as it descends, probably by the absorption of vapour, or of minute particles of water in the state of mist. Even at a level of 3 feet above the ground, there is said to be 2 per cent. less of rain than at the surface; at 20 feet, 12 per cent.; and at 50 feet, 23 per cent.

VII.—Rainfall in Mountainous Districts.

Accepting the foregoing results for the conditions of an open plain, it is known, on the contrary, that in mountainous districts the quantity of rainfall increases generally with the elevation. But the increase only takes place for a certain height, and then decreases. The reason of the greater rainfall on mountains is to be sought in the fact that the mountains are a mechanical hindrance, and force the air currents to rise. As the air rises it expands, and there-

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fore cools. This dynamic cooling is the chief cause of such rains, which are simply surplus moisture condensed and precipitated, and not the mixing of cold and warm layers of air. When the air begins to cool, the condensation is most rapid and the rain is heaviest. As the cooling proceeds the rain becomes lighter, and this probably explains the fact that in the highest regions of the Alps the snow falls only as fine needles of ice. The increase of rain with increase of height is due to the greater frequency of showers. The intensity decreases with the height, but the duration of the rain is lengthened. The zone of greatest rainfall in the Alps is probably at an elevation of about 6,500 feet above the sea, as indicated by the following Table, XIV., giving the distribution of rain on both sides of the Arlberg, given by Dr. Julius Han.*

TABLE XIV.—RAINFALL IN THE ALPS.

Station.	Arlberg.		Percentage of the Rainfall at Bludenz.		
	Height above the sea-level.	Rainfall.	Whole year.	Winter half.	Summer half.
	feet.	inches.	per cent.	per cent.	per cent.
Bludenz	1,837	40·8	100	100	100
Klösterle	3,478	59·4	127	140	121
Langen	4,003	72·0	154	180	144
Stuben	4,593	72·8	155		
St. Christof	5,873	74·4	160	193	142
St. Auton	4.200	46·8	100	116	91
Land·ck	2,657	24·0	51	44	53

The table shows that the rainfall increases with the height very quickly at first, and afterwards more slowly. Dr. Hann also gives the results of observations on the temperature on the Alps at various elevations, during the period 1851—1880, given in Table XV.

* "Minutes of Proceedings, Institution of Civil Engineers," vol. lxxxi., page 454.

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TABLE XV.—TEMPERATURE IN THE ALPS.

Place.	Height above sea-level.	Average temperature.		
		January.	July.	Whole year.
	Feet.	°Fahr.	°Fahr.	°Fahr.
Theodul Pass	10,925	9·0	34·7	20·5
Goldzeche Fleiss	8,990	16·0	40·3	27·9
St. Maria (Stelvio)	8,235	13·5	45·1	28·9
St. Bernhard	8,130	17·1	44·2	29·3
Säutis	8,097	16·0	42·1	28·4
Bergbau, Schneeberg	7,776	13·3	45·9	29·3
Obir	6,716	19·9	48·7	33 1
Schmittenhöhe	6,348	19·2	48·2	33·3
Vent	6,168	17·4	48·6	33·3
Sulden	6,037	19·2	51 1	34·7
St. Christof (Arlberg)	5,873	16·9	50·0	33·3
Schafberg	5,840	22·5	49·8	35·4
Sea-level	—	32—28·4	69·8	51·8
Average decrease of temperature per 100 metres (328 feet)	—	0·59	1·22	1·03
Increase in height for decrease of 1° Fahr. in temperature	—	547 ft.	273 ft.	318 ft.

It is clearly shown by the table that the temperature falls as the elevation is greater at the average rate of 1° Fahr. per 100 metres (328 feet). In certain large regions of the Alps, Dr. Hann says it may be taken as true that the temperature decreases in arithmetical progression according to the increase in the height. But the rate of decrease is much less in winter than in summer, as is shown in the table.

Dr. J. F. Miller has made many observations for the purpose of ascertaining the fall of rain upon the high mountains in Cumberland and Westmoreland, and to ascertain the increase or diminution which took place in relation to elevation above the sea. In his Annual Report for 1847 he drew the conclusion that, "as a general rule, in mountainous districts, the rain increases from the valley

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upwards, to an altitude of about 2,000 feet, and that above this altitude the quantity rapidly decreases." He gives the return for twenty-one months, as follows:—

	Elevation above the sea. feet.	Rainfall. inches.
The Valley, head of Borrowdale	160	170·55
Stye Head	1290	185·74
Seatoller	1334	180·28
Sparkling Tarn	1920	207·91
Great Gabel	2925	136·98
Sca Fell	3166	128·15

In explanation of such concentrated rainfalls, he says, "It may be stated that the Lake District valleys radiate from a series of mountains of slate and primitive rock, having the Gabel, 2,925 feet in height, as a nucleus or central point; in the immediate vicinity of which are Sca Fell and Pillar, respectively 3,166 and 2,893 feet in height, with Great End, Bon Fell, and Glaramara not much inferior in altitude. These mountains are distant only about 13 or 15 miles, in a direct line, from the Irish Channel; and, as no hill intervenes, they are fully exposed to our wet and prevailing winds, which are the south-west. The warm south-westerly current arrives at the coast loaded with moisture, obtained in its transit across the Atlantic. Now, our experiments justify us in concluding that this current has its maximum density at about 2,000 feet above the sea-level; hence it will travel onward until it is obstructed by land of sufficient elevation to precipitate its vapours, and, retaining a portion of the velocity of the lower parallel of latitude whence it was originally set in motion, it rapidly traverses the short space of level country, and with little diminution of its weight or volume; but on reaching the mountains it meets with a temperature many degrees lower than the point at which it can continue in a state of vapour; sudden condensation consequently ensues in the form of vast torrents of rain, which, in some instances, must descend in almost a continuous sheet, as when 9 or 10 inches are precipitated in

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forty-eight hours. When we reflect that a warm, moist current, perhaps only 3° or 4° above the point of saturation, in coming in contact with the mountain ridge, probably meets with a stratum of air 10° or 15° lower than its own inherent temperature, we shall cease to marvel that such quantities as 4, 5, or even 6 inches of water should be deposited in these localities in the course of a few hours. The mountains are, in fact, huge natural condensers, destined to force from the atmosphere the mighty volumes of water requisite for the supply of our lakes and rivers."

Herein Dr. Miller adopts the ordinary hypothesis that the cause of the condensation of vapour and its precipitation as rain is the mingling of the current with air colder than itself. The hypothesis of the up-lifting, by striking against the mountain, and the consequent expansion and cooling of the moist current, appears to be the more probable explanation of the sudden condensation and precipitation.

Mountain ranges, indeed, as Dr. Evans remarks, are the great condensers of atmospheric moisture, and the quantity of rainfall in any country is in the main dependent on the position of these ranges, and the prevailing direction of the winds. "India," he adds, "affords a good example of this fact, as the trade winds, or 'monsoons,' as they are there called, exhibit great regularity in their occurrence. From the end of October until the end of April there is little or no rain on the western coast, but during the other six months, after the monsoons have set in, rain falls in abundance. At Bombay, near the sea-level, the most rainy months are those of June and July, during which from 40 to 50 inches annually fall. During the whole of the rainy season the average of seven stations at the sea-level in the Bombay Presidency is about 80 inches. At an elevation of about 900 feet in the Southern Concan Hills, or Western Ghâts, there is an increase to about 135 inches, and at Mahabuleshwur, at a

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height of about 4,500 feet, and at a distance of 130 miles from the sea, the annual fall is over 250 inches. It is rarely that the hot stratum of aqueous vapour brought from the equator by the south-west monsoon floats at a higher level than this. In dashing against the precipitous western face of the Ghâts much of the warm stratum is thrown up among the colder layers of air at higher levels; but a little is carried eastward to be condensed by the Himalayas. So effectually does this high range do its work, that the great plain of Tibet to the east may be regarded as rainless. In the same manner, while the great central plain of Spain, at an elevation of 1,200 feet or more above the sea, is during the summer months pinched with drought, the seaward face of the mountains that skirt the Bay of Biscay are clothed with verdure, and are rarely in want of rain."

VIII.—Rainfall in England.

The rainfall in England is very various in quantity. Along the western shores the usual fall is from 40 to 50 inches, and in many districts from 50 to 75 inches. On the southern coast, the fall is from 30 to 40 inches, and in the eastern counties it is less than 25 inches. In exceptional positions—Seathwaite, in the hill country of Cumberland, for instance—the average rainfall is upwards of 140 inches; in the flats of Norfolk and Lincolnshire it is a little over 20 inches. In each year the variation in quantity of rainfall at the same place is often considerable. Dr. Evans mentions that in Hertfordshire there were 41 inches of rainfall in 1852, and less than 19 inches in 1854.

Mr. J. Glaisher gives the following table of the annual rainfall at the Royal Observatory, Greenwich, for each of the years from 1815 to the end of 1869*:—

* "Minutes of Proceedings, Institution of Civil Engineers," vol. xxxi., page 48.

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TABLE XVI.—RAINFALL AT THE ROYAL OBSERVATORY, GREENWICH.

Year.	Rain.	Year.	Rain.	Year.	Rain.
	Inches.		Inches.		Inches.
1815	22·5	1834	19·6	1852	34 2
1816	30·1	1835	24·9	1853	29·0
1817	29·0	1836	27·1	1854	18·7
1818	25·7	1837	21·0	1855	21·1
1819	31·1	1838	23·8	1856	22·2
1820	27·7	1839	29·6	1857	21·4
1821	34·5	1840	18·3	1858	17 8
1822	27·7	1841	33·3	1859	25·9
1823	27·1	1842	22·6	1860	32·0
1824	30·3	1843	24·6	1861	20·3
1825	24·6	1844	24·9	1862	26·5
1826	23·0	1845	22·4	1863	19·8
1827	24·9	1846	25·3	1864	16·8
1828	21·5	1847	17·8	1865	28·6
1829	25·2	1848	30·2	1866	30·1
1830	27·2	1849	23·7	1867	28·5
1831	30·8	1850	19·7	1868	25 2
1832	19·3	1851	22·7	1869	24·0
1833	23·0				

Here, likewise, very wide variations of rainfall from year to year are recorded—typical, in fact, of what is relatively as great in all other parts of the country. The average fall for all the years was 25·3 inches; and at times, for several consecutive years, as from 1819 to 1824, the fall for each year was above the average, whilst at other times, as from 1854 to 1858, the fall for each year was below the average. With a view to the designing of storage-reservoirs, Mr. Glaisher recommends as the safest principle to treat with the quantity of the water fallen in three consecutive years yielding the least, which is found to be nearly the average of all the years reduced by one-sixth. Thus, at Greenwich, the sum of the falls of rain in the three years ending 1857, namely 61·4 inches, being smaller than in any other three years in the period, or 20·5 inches average for the year; the total average, 25·3 inches, reduced by one-sixth, or 4·2 inches, is

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21·1 inches, which differs from the observed value by only 0·6 inches. Taking this result as a basis, the capacity of storage-reservoirs should be calculated for 200 days. With respect to evaporation, it appeared to Mr. Glaisher to amount to from 13 inches to 15 inches per year. By taking five-yearly averages, there is indicated a generally decreasing rainfall at Greenwich till the year 1859, but since then there is an increase:—

					Inches.
In five years ending		1819,	the average	annual rainfall was	27·68
,,	,,	1824	,,	,,	30·67
,,	,,	1829	,,	,,	25·84
,,	,,	1834	,,	,,	23·98
,,	,,	1839	,,	,,	25·28
,,	,,	1844	,,	,,	24·74
,,	,,	1849	,,	,,	23·98
,,	,,	1854	,,	,,	24·64
,,	,,	1859	,,	,,	21·68
,,	,,	1864	,,	,,	23·08
,,	,,	1869	,,	,,	27·28

The deficiency to 1859 was, therefore, in no way attributable to an excess of drainage or clearance of trees, for the amount of drainage within the last few years in question was greater than at any preceding period.

Mr. Glaisher's principle of treatment of the rainfall in respect of storage-reservoirs is also employed by Mr. Hawksley, in searching for what he calls the law of the minimum. "This singular thing comes out," he says, "which is true within the smallest possible fraction of all long-series rain-gauge observations, extending over not less than twenty years—that if the average of, say, twenty years is taken, and from that average one-sixth is deducted, the average of three minimum dry years will be obtained within the fraction of a single inch. That quantity may then be relied on as the probable rainfall. The amount of loss or evaporation has then to be ascertained, according to the particular district. That loss varies in these islands from 10 inches per annum as a minimum, to 18 inches as a maximum. The minimum occurs very rarely, indeed only in the case of bare

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precipitous mountains, consisting of non-absorbent rock, such as slate or granitic rock. From that surface all the rain that falls can be gathered, with the exception of about 10 inches. But the case is very different when the surface is covered with soil and peat, where it becomes flat moorland on the summit, and more so where the land is cultivated and thrown into the character of a sponge. In general, however, with mountain watersheds, where the intermediate condition exists, the actual ascertained loss amounts to from 13 inches to 15 inches per year, according to the situation and some local circumstances, and may be taken at a mean of about 14 inches per year." *

As a practical illustration, Mr. Hawksley took the case of Sheffield, where a population of a quarter of a million was entirely dependent upon mountain watersheds. There were correct records for forty years, from which it was known that, upon the average, the fall of rain had been 39½ inches annually. Deducting one-sixth, there remains about 33 inches; and taking from that 14 inches as the loss from what is called evaporation, there are left 19 inches, which is the actual quantity received into the storage reservoirs on an average of three dry years.

Mr. G. J. Symons has arrived at the following conclusions, based on the observations of a great number of years, on the rainfall in Great Britain:—

1. The wettest year will have a rainfall of nearly half as much again as the mean.

2. The driest year will have one-third less than the mean.

3. The driest two consecutive years will each have one-quarter less than the mean.

4. The driest three consecutive years will each have one-fifth less than the mean.

At places where the average rainfall is large, the ex-

* "Minutes of Proceedings, Institution of Civil Engineers,' vol. xxxi., page 54.

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tremes both of wetness and of dryness will be less pronounced than at those places where the usual rainfall is small.*

Mr. de Rance has given a hydro-geological map of England, in which he has divided the character of the soil into four divisions: the impermeable; the partially porous; the supra-pervious, or clays resting on permeable rocks; and the permeable. In comparing this map with the Hyetographical or Rainfall Map, prepared by Mr. G. J. Symons, it is seen that the areas of greatest rainfall correspond with those of the impermeable rocks. These harder rocks, having been better able to withstand the wear and tear of rain and rivers, and other denuding forces, are, as Dr. Evans remarks, at a higher level, and are brought into closer contact with the water-yielding clouds than the districts of softer rocks at a lower level. Roughly speaking, the western part of England and Wales consists of impermeable and partially porous rocks, and the eastern parts of supra-pervious and permeable soils.

IX.—Percolation and Evaporation of Rainfall.—Mr. Dickinson's and Dr. John Evans' Observations.

The first to make experiments on the subject of the proportion of percolation of rain through 3 feet of soil to the rainfall at the surface were Dr. John Dalton and M. Maurice, of Geneva, about the end of last century. The late Mr. John Dickinson was the first in England to repeat the experiments of Mr. Dalton. His observations began in 1836, but new gauges, formed of cast iron, were fixed at Nash Mills, Hemel Hempstead, in 1853, and have been in continuous operation ever since, under the direction of Dr. J. Evans. These are two receivers, or cast-iron cylinders, 18 inches in diameter and 3 feet in length, turned to a knife-edge at the top, and sunk to a depth of 3 feet below the level of the ground in which they are placed, so that

* "British Rainfall, 1883," page 32.

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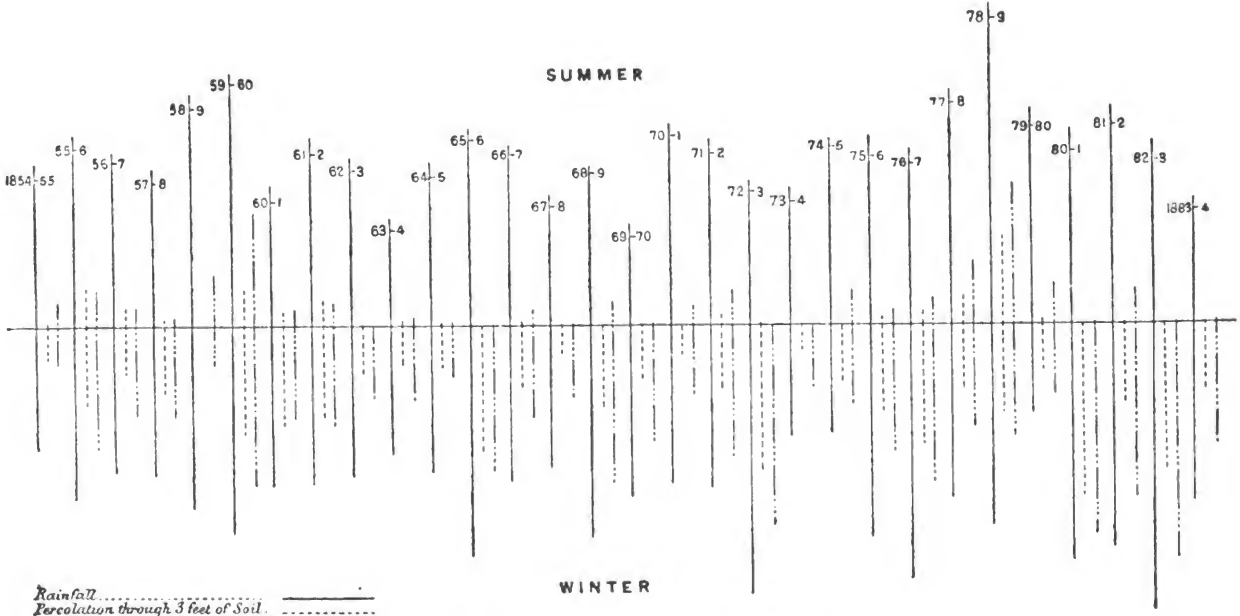

Fig. 58.—Rainfall, Evaporation, and Percolation at Hemel Hempstead, 1854—1884.

the edge just projects upwards. One of the cylinders is filled with the ordinary surface soil of the neighbourhood, and the other with fragmentary upper chalk. Grass grows on the upper surface of the contents of the gauges, and also on the ground surrounding the cylinders. The rainfall is observed in the immediate neighbourhood of the percolation gauges, and the register is made up at 9 a.m. The winter half of the year is considered to commence on the 1st October, and the summer half on the 1st April.

Dr. Evans has arranged the results of thirty years' observations in a diagrammatic form, reproduced on a smaller scale in Fig. 58, and also in a table, page 137.* The plain vertical lines in the diagram show the rainfall in each year from October 1 in one year to September 30 in the following year, the winter rainfall being shown below the central horizontal line, and the summer rainfall above it. The percolation through 3 feet of soil is shown in a similar manner by broken vertical lines, and the percolation through 3 feet of chalk by broken and dotted lines. The corresponding numerical values are given in the accompanying Table XVII.

The average results of the thirty years show that out of a total rainfall of 27·843 inches yearly average, 6·519 inches, or 23·4 per cent., passed through 3 feet of soil, and 10 650 inches, or 38·6 per cent., through 3 feet of chalk.

The percolations during winter and during summer are in marked contrast. Out of the winter rainfall of 13·752 inches, the percolations were 5·707 inches and 8·532 inches. Out of the summer rainfall of 14·091 inches, on the contrary, when vegetation was in progress and evaporation was greater, there were but ·812 inch and 2·118 inches respectively. The variations in the proportion of the percolation to the rainfall are very great, even in the winter half-year, so much depending upon the manner in which the rain falls, and whether it is con-

* From a lecture on "Physiography," by John Evans, D.C.L., LL.D., at the Institution of Civil Engineers, session 1884–85.

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TABLE XVII.—Observations at Nash Mills, Hemel Hempstead.

Year.	Winter.			Summer.		
	Rain.	Percolation.		Rain.	Percolation.	
		Soil.	Chalk.		Soil.	Chalk.
1854–55	9·32	2·45	3·45	12·66	0·19	2.30
1855–56	14·48	6·82	10·47	14·86	2·79	3·09
1856–57	11·96	3·72	7·19	14·11	1·11	1·32
1857–58	11·81	5·64	7·16	12·27	0·80	0·84
1858–59	9·64	0·09	2·69	18·31	..	4·22
1859–60	16·49	9·27	12·44	20·40	3·16	8·94
1860–61	11·56	7·61	7·55	10·38	1·13	1·02
1861–62	12·63	7·42	8·19	14·37	2·39	1·77
1862–63	11·01	3·56	5·50	13·40	..	0·19
1863–64	9·24	3·18	5·89	8·42	0·35	0·45
1864–65	10·93	3·42	3·55	12·60	..	..
1865–66	20·00	10·47	12·05	15·59	0·03	0·20
1866–67	12·60	4·64	6·97	14·37	0·18	1·39
1867–68	11·36	2·03	5·36	10·05	0·04	0·42
1868–69	17·58	7·64	11·21	12·80	0·02	2·00
1869–70	13·33	4·50	8·76	7·59	..	..
1870–71	12·54	2·08	5·35	16·09	..	1·72
1871–72	11·25	4·65	9·50	14·44	1·00	2·70
1872–73	21·55	11·25	16·05	11·29	..	..
1873–74	8·91	1·86	4·40	10·71	0·05	0·65
1874–75	11·69	4·15	5·57	15·00	..	3·46
1875–76	17·28	6·08	10·29	14·25	0·50	1·15
1876–77	20·69	10·13	11·77	13·74	1·04	1·60
1877–78	13·74	4·00	8·91	18·49	2·16	5·11
1878–79	14·62	5·75	7·94	25·09	6·94	12·82
1879–80	5·84	2·79	4·28	16·40	..	3·20
1880–81	20·07	13·59	16·36	14·85	..	..
1881–82	14·82	6·24	11·38	16·52	0·48	2·64
1882–83	22·67	11·67	17·16	13·94	..	0·33
1883–84	12·95	4·53	8·56	9·76	..	..
	412·56	171·23	255·95	422·72	24·36	63·53
Average of thirty years .	13·752 14·091	5·707 0·812	8·532 2·118	14·091	0·812	2·118
Yearly average	27·843	6·519	10·650			

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stant for some days or intermittent. Compare, for example, the winters of 1879-80, and 1870-71 :—

	Winter 1879-80. Inches.	Winter 1870-71. Inches.
Rainfall	5·84	12·54
Percolation through soil .	2·79	2·08
,, ,, chalk .	9·28	5·35

Less rain percolated through the soil in 1870-71, though there was more than twice the rainfall, and there was very little more percolation through the chalk. There are many other contrasts in the table. For another instance, in the summer of 1858-59, 18·09 inches gave no percolation, whilst in that of 1877-78, 18·46 inches gave 2·16 inches of percolation through soil.

Dr. Evans insists that in the case of water-supply derived from porous soils, it is in the highest degree illusive to depend upon averages. The minimum, or, at the best, the lowest average of three successive years, is the utmost that can be relied upon. Taking the three years 1862-64, a rainfall of about 22 inches yielded only 3½ inches of percolated water. In the three years 1869-71, 25 inches yielded little more than 4 inches through soil.

Dr. Evans thus sums up the principal points which concern the engineer with reference to rainfall and water-supply:—

1. That the higher the level and the nearer the sea, especially on the western coasts, the greater is the rainfall.

2. That in the high districts the rocks are, as a rule, more impermeable than in the low districts, and the supplies to the streams larger and more immediate.

3. That in the low-lying and eastern districts the rainfall is small and the rocks for the most part absorbent.

4. That, while providing means for receiving and dealing with the maximum amount of supply, reliance can only be placed on the minimum, and not on the average.

5. That though, in the case of permeable soils, the absolute minimum of percolation may be disregarded, yet that

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the average of three years seems to show that not more than 4 or 5 inches of the annual rainfall can safely be regarded as available for the supply of both the wells and rivers of the district.

6. That any water abstracted from wells in a permeable district is so much abstracted from the sources of the neighbouring streams, though in many cases it can be and is returned to them after use.

X.—Rainfall and Percolation.—Mr. Charles Greaves's Observations.

The late Mr. Charles Greaves, ever since the year 1852, felt it very desirable to confirm the researches of Mr. Dickinson and Dr. Evans on the percolation of rain through a medium representing natural soil, and he resolved to establish a gauge-register similar to theirs. In 1851, the gauge was set at Lee Bridge, in the valley of the river Lee, 6 miles north and 1½ miles west of the meridian of Greenwich, at 10 feet above Trinity high-water level. But the register was only maintained continuously since the beginning of 1855. The gauge, Figs. 59 and 60, is on the principle of the Dalton gauge. It consists of a water-tight box of slate, open-topped, 3 feet square and 3 feet deep, the bottom of which is slightly coniform towards the centre, where a lead pipe is connected, leading to another vessel set upright as a receiver, at a level several feet below the tank. A glass gauge is fixed to the side of the receiver, with a stopcock and a graduated scale. The slate box, or tank, is sunk into the ground and is filled with soil or earth to within 2 inches below the top. The soil was intended to resemble common Hertfordshire land, and was made up of soft earth, with loam, gravel, and sand—all well mixed together beforehand and trodden in. It was turfed over and was kept level, the grass being occasionally cut. Nothing is done to lighten the soil, and worms are sometimes

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seen. The water collected in the receiver never rises to the level of the bottom of the tank, and the soil of the tank is, in fact, under-drained. The "Dalton gauge" has no overflow, and water has never been seen to accumulate on the surface of the earth or grass—fulfilling the intention

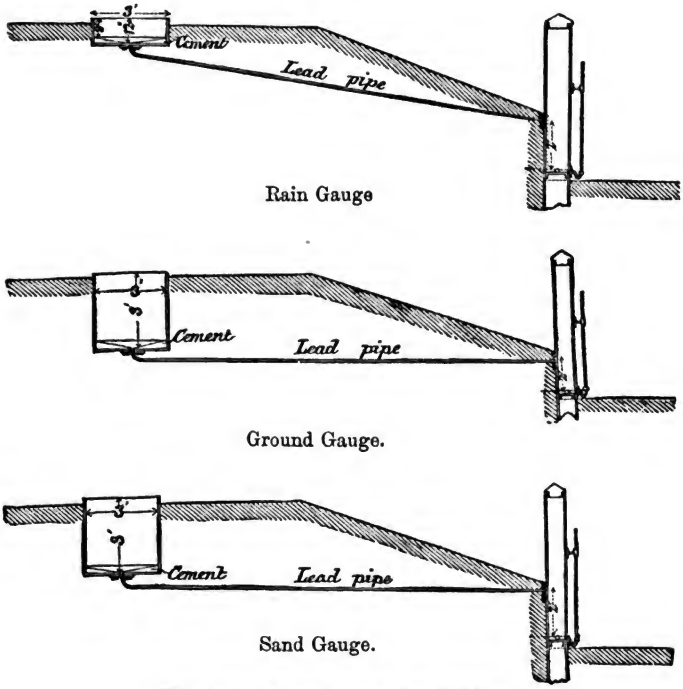

Fig. 59.—Dalton Gauges, Lee Bridge.

that all rain that falls on the gauge should soak into the soil.

A rain-gauge of equal superficial area, but only 1 foot deep, was fitted at the same time beside the Dalton gauge. The gauges are under like conditions in all respects.

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In the year 1860 another gauge, similar to the Dalton gauge, was fixed, with the view of getting a definite maximum of percolation. It was for this purpose filled entirely with fine sand, such as is used in the filter-

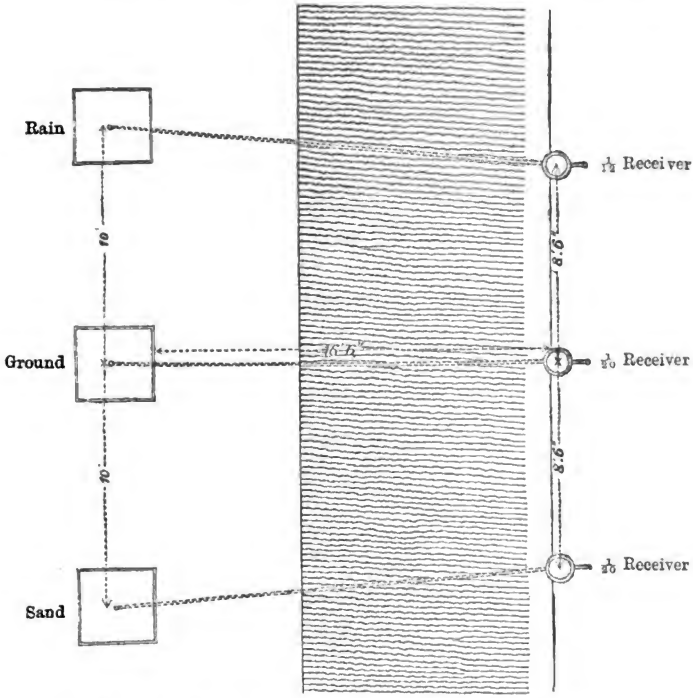

Fig. 60.—General Plan of the Dalton Gauges, Lee Bridge.

beds of water-works. The sand is under-drained, like the soil.

In addition to these gauges, by means of which the rainfall, the percolation, and, by deduction, the evaporation, from sand and from turf could be determined, a

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similar gauge, Fig. 61, 3 feet square and 1 foot deep, was launched in 1859, and has been kept afloat, and partly immersed, in a quiet part of a flowing stream. The surface of water within it is always below that of the water without, and the most suitable depth is from 3 inches to 7 inches. It is exposed in all weathers, and any addition or abstraction of water, only made when necessary, is duly recorded. Thus, by combining the obser-

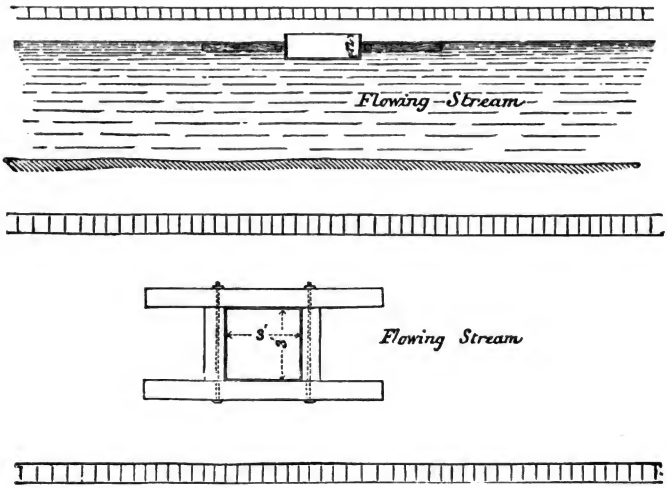

Fig. 61.—Floating Gauge, Lee Bridge.

vations in the ordinary closed rain-gauge with those of the floating gauge, an absolute measure of evaporation from a water-surface, representing, approximately at least, the surface of a river, a lake, or a reservoir, is obtained.

The summary results of fourteen years' observations are given in Table XVIII. following.*

* From a Paper "On Evaporation and on Percolation," by Mr. Charles Greaves, in the "Minutes of Proceedings, Institution of Civil Engineers," vol. xlv., page 33.

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TABLE XVIII.—Summary of Fourteen Years' Observations on Rainfall, by Mr. C. Greaves, 1860–73.

Year.	Rainfall.	Percolation.		Evaporation from.			
		Soil.	Sand.	Soil.	Sand.	Floating-box. R = rise E = fall.	Water.
	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.
1860	32·558	10·761	23·456	21·797	9·102	11·500 R	21·058
1861	23·633	5·711	16·360	17·921	7·273	1·375 E	25·008
1862	26·581	8·549	21·178	18·031	5·402	9·250 R	17·332
1863	19·766	3·761	16·411	16·004	3·353	1·500 R	18·266
1864	15·891	3·824	12·636	12·067	3·255	2·750 E	18·640
1865	29·248	11·150	27·823	18·098	1·425	9·125 R	20·124
1866	31·697	12·587	28·112	19·110	3·585	12·875 R	18·821
1867	27·436	5·162	22·424	22·274	5·011	7·375 R	20·061
1868	23·308	7·112	20·200	16·196	3·108	3·625 E	26·933
1869	24·562	8·050	22·138	16·512	2·425	5·500 R	19·062
1870	20·395	7·225	18·700	13·170	1·696	R = E	20·396
1871	24·083	6·188	20·087	17·895	3·996	4·500 R	19·583
1872	37·166	12·025	30·050	25·141	7·116	14·250 R	22·916
1873	23·770	4·050	20·120	19·721	3.650	3·375 R	20·395

The accuracy of the records summarised in this table is confirmed by those of neighbouring rain-gauges, as published by Mr. G. J. Symons. The average fall of rain at twelve stations in London, for the seven years 1864 to 1870, was 24·486 inches; and at Lee Bridge for the same period the average fall recorded was 23·934 inches.

Only in three years out of the fourteen years above tabulated has the evaporation from water exceeded the rainfall—in 1861, 1864, and 1868. In 1870 it was the same, and in the remaining years the rain was in excess of the evaporation. The rise of water in a supposititious tank, open for rain as well as for evaporation, was 71·5 inches in fourteen years, or a net gain of 5·1 inches of rain per year. The percolation through ordinary soil has been 26·57 per cent. of the rainfall in 22 years, and the evaporation 73·42 per cent. of the rainfall: roughly stated, in the proportion of one-fourth and three-fourths respectively.

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The evaporation from a surface of water was 77·77 per cent. of the rainfall, though it occasionally exceeded the rainfall.

The fluctuations of action are notable. Whilst the annual rainfall varies from 37·166 inches in 1872 to 15·891 inches in 1864, or in the ratio of 2·33 to 1, the annual percolation through soil varies in a still higher ratio, as 3½ to 1, from 12·587 inches to 3·761 inches in fourteen years. But through sand the percolation varies only as 1¾ to 1, from 30·050 inches to 12·636 inches. The evaporation from a surface of water varied only from 26·933 inches to 17·332 inches in fourteen years, or as 1·55 to 1. But it is the intermittent character of the percolation, and its total absence in summer, as exhibited in the detailed tables given in Mr. Greaves's paper, which are specially notable.

A great degree of percolation supervenes on the thawing of snow, and the greatest is due to frequent thaws of small falls of snow. For many consecutive months, often, there is no percolation whatever, and the monthly range varies from 3½ inches to nothing. Five times there has not been any percolation for seven consecutive months, twice for six months, and only in one year, 1860, has there been percolation every month.

Mr. Greaves summarised his results and conclusions as follows: the magnitude of percolation through sand at all times; the smallness of percolation through earth or soil on the whole; the consequent magnitude of evaporation; the entire absence of percolation in warm summer weather; the excess of evaporation from ground over evaporation from a surface of water in winter, and from a surface of water over evaporation from earth in summer; the small thickness of earth (24 inches) under which water may be considered safe from loss; great variations observable in the yearly percolation, the maximum reaching eleven times the minimum.

Mr. Greaves deduces an artificial table for the home

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counties of what may be expected from month to month for an average year as follows :—

TABLE XIX.—Artificial Table of the Rainfall that may be expected for an Average Year, in the Home Counties.

Month.	Average rainfall.	Average percolation through sand.	Average percolation through earth or soil.	Average rise or fall in floating box.
	inches.	inches.	inches.	inches.
January	2·000	1·875	1·250	2·500 R
February	1·375	1·250	·750	1·875 R
March	1·750	1·625	·750	1·125 R
April	1·500	1·250	·250	·750 R
May	2·250	1·875	·125	·250 R
June	2·125	1·625	·125	2·750 R
July	2·125	1·125	·125	2·250 R
August	2·625	2·000	·125	1·500 R
September	2·125	1·625	·250	1·000 R
October	3·000	2·375	·750	1·500 R
November	2·125	2·000	1·250	2·000 R
December	2·000	1·375	1·250	2·500 R
Whole year	25·000	20·000	7·000	4·500 R

According to this table, of 25 inches of rainfall, 7 inches percolates through soil, leaving 18 inches, or 72 per cent., evaporated. From a surface of water, represented in the floating box, as there is only 4½ inches of rise out of 25 inches of rainfall, the remainder, 21½ inches, or 82 per cent., is evaporated.

XI.—Rainfall and Percolation. Observations of Messrs. Lawes and Gilbert.

Messrs. Lawes and Gilbert made observations on rainfall and percolation during the five years from September, 1870, to August, 1875, at Rothamstead, Herts. The soil was rather heavy loam with clay subsoil in its natural state of consolidation. They took the soil just as it was; they dug down and undermined it, placing perforated iron plates underneath, and having underpinned it, they built it in an

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isolated square with brick and cement. Three such gauges were constructed, having each an area of one-thousandth of an acre, or 43·56 square feet, forming a square of which the length of the side is 6·60 feet. One was 20 inches deep, another 40 inches, and the third 60 inches deep. The general results are given in Table XX., following. The second part of the table expresses the percolation and evaporation "as percentage of the rainfall." *

TABLE XX.—RAIN AND PERCOLATION AT ROTHAMSTEAD, HERTS, 1870–75.

YEAR.	Rainfall.	Percolation through soil.			Difference reckoned as evaporation.		
		20 ins. deep.	40 ins. deep.	60 ins. deep.	20 ins. deep.	40 ins. deep.	60 ins deep.
	inches.	inches.	inches.	inches.	inches.	inches.	inches.
Sept. 1870 to Aug. 1871	27·55	9·64	9·42	5·81	17·91	18·13	21·74
„ 1871 „ 1872	29·02	9·69	9·40	8·24	19·33	19·62	20·78
„ 1872 „ 1873	30·66	14·35	13·67	12·03	16·31	16·99	18·63
„ 1873 „ 1874	21·69	5·47	5·11	3·61	16·22	16·58	18·08
„ 1874 „ 1875	30·74	12·25	12·72	10·30	18·49	18·02	20·44
Average per year	27·93	10·28	10·06	8·00	17·65	17·87	19·93
		per cent.	per cent.	per cent.	per cent.	per cent.	per cent.
Average per year	27·93	36·8	36·0	28·6	63·2	64·0	71·4

Of the average rainfall, say 28 inches, it appears that only 8 inches percolated through 60 inches of soil, whilst 10 inches and 10¼ inches percolated through 40 inches and 20 inches respectively, pointing to the conclusion that capillary action had influence on percolation, or rather on evaporation, much below the depth supposed by Mr. Greaves. In fact, taking the observations in detail, it was evidently operative below 40 inches of depth. Beginning in September, after comparatively dry and warm weather, less water passed through 40 inches than through 20 inches,

* "Minutes of Proceedings, Institution of Civil Engineers," vol. xlv., pp. 59, 60.

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and less through 60 inches than through 40 inches; and so it went on until the winter rains accumulated, when the reverse happened, and there was sometimes more percolation through the 60 inches than through the 20 inches.

XII.—Influence of Forests on Rainfall.

It is supposed that the wholesale destruction of the woodlands formerly existing in countries bordering the Mediterranean Sea has been, in part at least, the cause of the present desiccation of these districts, by removing forests and laying bare to the sun and to winds surfaces which were previously kept cool and damp under trees.

Special observations have been made with a view to the determination of the difference of rainfall and evaporation, if any, between an open and a wooded country. The stations were selected, one in the forest of Halatte, and one at the same level in an open country about 1,000 feet distant from the forest station. The rainfall over the forest was 18 inches, or 1·35 inches more than the rainfall in the open, for the eleven months, February—December, 1874. The rainfalls over the forest, in the open, and under the trees, were respectively as 100, 92·5, and 62. But the loss by evaporation under the trees was only one-third of that in the open, which amounted to 70 per cent., and, therefore, the effective rainfall in the forest was 44 per cent. more than in the open. In this case it appeared that the forest was instrumental in largely supplying watercourses.

From the results of hygrometric observations, it appeared that there was more moisture in the air over the forest than in the open, especially in the month of May.

In North America, on the contrary, it is maintained that there is nothing in the river records to establish any theory either for increase in height of floods or for less low-water discharge due to the destruction of forests.*

* See an abstract of a paper on the "Destruction of Forests," by T. P. Roberts, in the "Minutes of Proceedings, Institution of Civil Engineers," vol. lxxix., page 407.

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However that may be, there are conditions under which the rainfall is materially influenced by forest. Sir W. Denison mentions a curious instance of this influence in India. The Western Ghauts, which run parallel to the coast of the peninsula at a distance of from 50 to 60 miles, had a break in them of about 40 miles in width, through which the railway from Madras to the west coast is taken at a level of 1 200 feet above the level of sea. About 20 miles below the crest of this slope, the railway leaves a dry, bare-looking country, and dashes at once into a rich-looking bamboo jungle, where the vegetation was most luxuriant. It was found that although the south-west monsoon passes with full force through this gap in the range of hills, the rain stopped at this line of jungle; that at a distance of a few hundred yards to the west of the line there was probably a depth of 60 inches of rainfall in three months, while at the same distance on the east side of the line there was 6 inches of rainfall. It happened, on inquiry, that the line of no rain had travelled backwards a distance of 7 miles in the course of twelve years; that when the forests were cut down and the ground laid bare to the action of the sun, the rain ceased. It is said in explanation that the sun during the south-west monsoon is almost vertical, and shines down on the bare dry soil, creating by its heat an upward current of hot dry air, which, encountering the rain, turns it into vapour, which is carried away by the south-west wind, bestowing here and there a shower when it passed over forest-land, but never descending again in any body till it reaches the Bay of Bengal.

XIII.—Drainage in the Fen Districts.—The Ancholme. —Principles established. — The Bedford Level, South, Middle, North.—St. Germains Sluice and Syphon.

In the reign of Charles I., about the year 1639, it was first determined to drain the great level of the fens, an

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extensive district of low marshy land about the river Ancholme, on the east coast of England, bordering upon the river Humber; with the Bedford Level, so called after the Earls of Bedford, probably at first an estuary of the Wash, into which the rivers Witham, Welland, Glen, Nene, and Ouse were discharged, with the valley of the Witham also draining into the Wash. In the north of Lincolnshire the fens do not extend more than 4 or 5 miles inland; in the south of that county they are 20 miles in width; and between Peterborough and Lynn, which is the widest part, they are 30 miles wide. The fens terminate a few miles south of Ely, and the whole length of the district is about 130 miles.

With the exceptions of the Lincolnshire Wolds to the north, and a small tract which penetrates it to the south and south-west, the whole fen district has nearly one level, much of which is beneath that of the sea, especially about its middle and southern parts. The water flowing into and falling upon so extensive an area from elevations too small to impel it onward, would naturally be arrested in a marsh, the lowest point of which was midway south of Ely, and the whole length of the district is about 130 miles.

The drainage works of the Ancholme Level in the north of Lincolnshire, executed in conformity with the terms of Sir John Rennie's report, have already been described, page 52. Sir John Rennie briefly indicates the leading principles of drainage thus practically established:—

1. The formation of catch-water drains, by which the high land waters were separated from the low land waters, and each class of water was conveyed to independent sluices at the lowest practicable outfalls. This system was first practised by Mr. Rennie about the year 1801 in the Witham drainage.

2. The straightening, deepening, and general improvement of the main river, separating as much as possible the navigation from the drainage.

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3. The formation of overfalls, weirs, and reservoirs, for arresting the sand and mud, and preventing the drains from being choked between the sea and their inland borders. The result was a large fresh-water estuary which for many ages was probably the sole characteristic of the fen.

The principal rivers forming the water-drains to this district are, the Witham, the Welland, the Nene, and the Ouse. The Nene and the Ouse, both of which rise in the same county, take directions nearly at right angles to each other, and discharge themselves into the Wash within a few miles of each other. The river Ouse is tortuous. Its main branch rises at Gentworth, about 10 miles from Buckingham, which is 80 miles from Lynn; but the river passes over about 160 miles in its course. The river Nene originates in two springs, north and south of Daventry. Its course is easterly to Northampton, where it becomes navigable. The direct distance to the outfall at the sea is 60 miles; but the course of the river is nearly 100 miles in length. At Peterborough it enters the fens, being chiefly conducted through this region by artificial cuts, so that its original channels are in some cases hardly traceable. The valley of the Nene is lost 30 miles before it falls into the sea; that of the Ouse extends no farther than St. Ives, and the river runs a course afterwards of 50 miles to the outfall at Lynn. It is apparent that these and other rivers all seek a common outlet, over lands which are no higher than their beds, and are only prevented by embankments from distributing themselves over the soil. The extent of country drained by the Wash comprises altogether about 5,000 square miles.

The region of the Bedford Level, a plan of which is given in Fig. 62, extending between Peterborough and King's Lynn, is divided into three parts—the South Level, the Middle Level, and the North Level. The South Level is drained by the Ouse and the Bedford rivers, which, as well as the Well Creek, have been variously treated. The first appliance, Denver Sluice, placed at the confluence of these

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rivers, by keeping up the water of the Bedford River to a

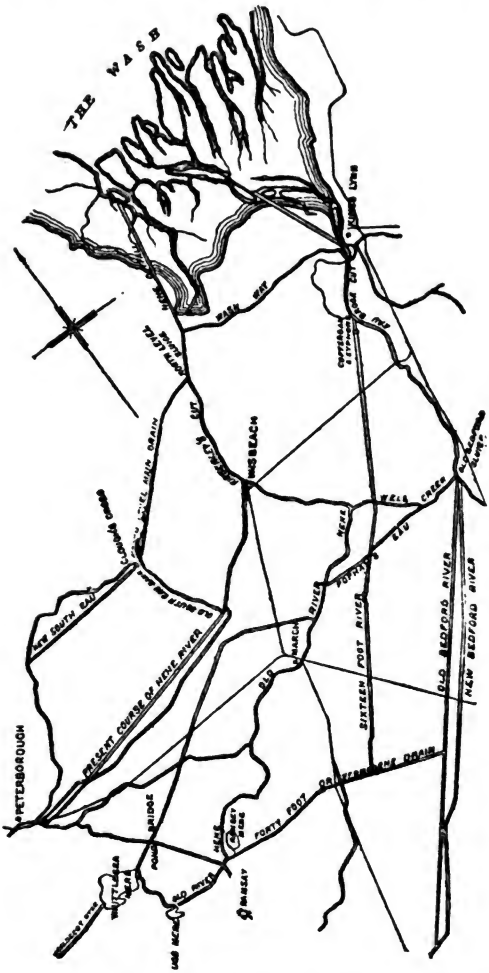

Fig. 62.— Bedford Level.

higher level, caused all the fens in the district to be flooded.

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In 1713, the sluice was carried away, after which, by the silting up of the Ouse, the South Level became more flooded than before. In 1750, the sluice was reinstated by Labelyere, and as the harbour of Lynn still suffered from accumulations of sand and silt, it was proposed to straighten the Ouse by cutting off a bend in the river above the harbour, in order to shorten the course of the river from 7 miles to 3 miles, thereby giving a greater fall as well as a greater depth of outfall. For these objects, the Eau Brink Cut was constructed and was opened in 1821. It answered expectations, lowering the low water at its upper end by 6 or 7 feet, and improving the navigation up to and in the harbour of Lynn. In consequence, the cills of Denver Sluice were lowered 6 feet, and the tide, which before hardly lifted itself in the Bedford River, now penetrates almost to the end of it. This river was considerably deepened, and the channel of the Ouse, previously much silted up below Denver, was speedily cleansed in consequence of the increased speed and volume of tide that swept through it. The cost of the Eau Brink Cut was £600,000; it is rated upon the lands drained by the rivers having their outlet into the Ouse, which amount to 250,000 acres, including a portion of the Middle Level.

The North Level was for many years drained by the crooked course of the old Nene River, the internal drains being kept cleared, as far as possible, when there was was not a good outfall. The Nene, in consequence, continued to silt up, and became less and less capable of discharging the waters, not only from the back country, but also from the lands along its banks.

The first attempt at improving the outfall was proposed by Kinderley, in 1721. In 1770, after four breaches of the banks of the Wisbeach River had been made, a cut commencing five miles below Wisbeach was completed, but it was only 1½ miles in length. Though it was only half of what had been proposed by Kinderley, it directed attention to the root of the evil. It was soon found that

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the immense sandbanks immediately below the cut, which had been partly cleared away by the operation of the cut, began to accumulate to such an extent, as early as 1804, as to cause great anxiety, while the navigation to Wisbeach was unsatisfactory: for large shipping it was destroyed. Reporting in 1814, Mr. Rennie showed that, according to the levels taken by him, the fall on the 5¾ miles from Wisbeach Bridge to Gunthorpe Sluice was only 6 inches, but from the Sluice to Crabhole, on the Nene Outfall, a distance of about 5½ miles, the fall was 13 feet. A new channel, called the New Cut, on the Nene Outfall, was constructed from Gunthorpe Sluice to Crabhole, and the water was turned into the new passage in 1830. The effect of the scour so produced upon the sides and bottom of the cut was so great that it was necessary to protect the banks with a large quantity of stonework. The dimensions of the New Cut at the lower end, at Crabhole, and at the upper end, at Kinderley's Cut, were as follows:—

	Lower end. feet.	Upper end. feet.
Width at the top . . .	270	200
Do. bottom . .	165	135
Depth	24	24

There is a regular depth of 8 feet below low water. The cost of the New Cut, or Nene Outfall, from Kinderley's Cut to Crabhole, was £200,716. As soon as this work was accomplished, a new sluice was constructed to discharge the waters of the Level into the Nene, the cill of which was laid 5 feet deeper into the old channel than the one which was superseded by it, and the opening for waterway was 36 feet wide, instead of 17 feet as formerly. The North Level Main Drain in connection with this sluice was formed in a south-westerly direction up to Clough's Cross, a distance of 8¼ miles, 8 feet deeper than the Old Sluice Drain, and of six times its capacity. From Clough's Cross the new drains diverge into two lines, called respectively the New South Eau and the New Wryde, which receive the

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waters from every district of the North Level, including the Newborough, Borough Fen, and Great Portsand. When the works were opened in 1834, their efficacy was found to surpass the most sanguine expectations. The opening of the Nene Outfall had the effect of adding from 10 feet to 12 feet to the depth of water in the river at Wisbeach, solely by the action of the scour occasioned by the lowering of the outfall. The trade of the town was increased from 55,040 tons in 1829 to 63,180 tons in 1830, and to 167,443 tons in 1847.

The total sum expended on the later works was upwards of £100,000, and the area drained is 200,000 acres. Land which, previous to 1848, was only worth £5 per acre, would then fetch from £60 to £70 per acre.

The MIDDLE LEVEL presents a much more complicated system of drainage than the other levels, having a network of leams, drains, eaus, and rivers, running in all directions, in some cases at right angles to the outfall, and in others in a contrary direction. The principal artery of this area is the old river Nene, from which an embankment alone separates it. The river takes a very circuitous course: it runs through Whittlesea, Ugg, and Ramsey Meres, and thence to March and Upwell, where it is connected with the Ouse by a junction with Popham's Eau and Well Creek. It had for many years past been a source of contention between those using it as a navigation and the owners of land requiring to make it available for drainage.

In 1842, Mr. James Walker reported on the drainage of the Middle Level, affecting an area of 140,000 acres, exclusive of the high lands about Whittlesea and March. With the exception of these lands, the whole of this vast area was drained by artificial means. He proposed a main line of drain to commence at the upper end of the Eau Brink Cut, above the Marshland Sluice, to Caldecot Farm, on the west side of Whittlesea Mere, to be level for its whole length, 31 miles; but it was only partly constructed. It is called the Middle Level Drain, or Walker's Cut, Fig. 63,

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extending 11¼ miles from the junction with the Eau Brink Cut, and communicating with Popham's Eau and the Sixteen Feet River, which are two of the main drains of the Middle Level. A sluice, known as the St. Germains Sluice, was built at the outfall or confluence of the main drain with the Ouse.

Fig. 63.—Section of Middle Level Drain, near its lower end.

As at first made, in 1847, Walker's Cut was 50 feet wide at the lower end, 40 feet wide at Well Creek, and 30 feet wide above Well Creek. The level of the bottom, at the outlet, was 5 feet below low water in the Ouse, and that of the cill was 8 feet below. It inclined upwards at the rate of 1 inch per mile to Well Creek, where sluices were placed to keep up the level of the water in this river for navigation. The cills of the sluices were laid at the same level as that of the outlet sluice at the upper end of Eau Brink Cut, and they consisted of three openings of 20 feet each. In 1848, it was determined to deepen all the main rivers and drains of the Middle Level, with a few exceptions, for a length of about 110 miles, by from 4 feet to 6 feet, with widths at the bottom of from 12 feet to 30 feet; to make new cuts or junctions, and to construct locks at Upwell, Horsway, and Ashline, for navigation. In consequence of these works, which were completed in 1852, the water in the rivers and drains was lowered 6 feet.

In 1857, Mr. Walker's original design was further carried out by the deepening of Walker's Cut 4 feet, or to 1 foot below the cill at the outlet, with a level bottom for its whole length of 11¼ miles. The width at the bottom, thus deepened, was 48 feet. The slopes of the sides are 2 to 1 feet, and, according to Sir John Hawkshaw, writing in 1863, the level of the bottom is 7 feet under low water

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of spring tides in the river Ouse, at the point where the drain enters the river. The rise of the tide in the Ouse at that point is about 19 feet at spring tides, and the level of the cill of the St. Germains sluice is 6 feet below low-water of spring tides. The bed of the drain at this place is of soft blue clay, and the sides consist of variable thicknesses of soft blue clay, peat, yellow clay, and surface soil. Of

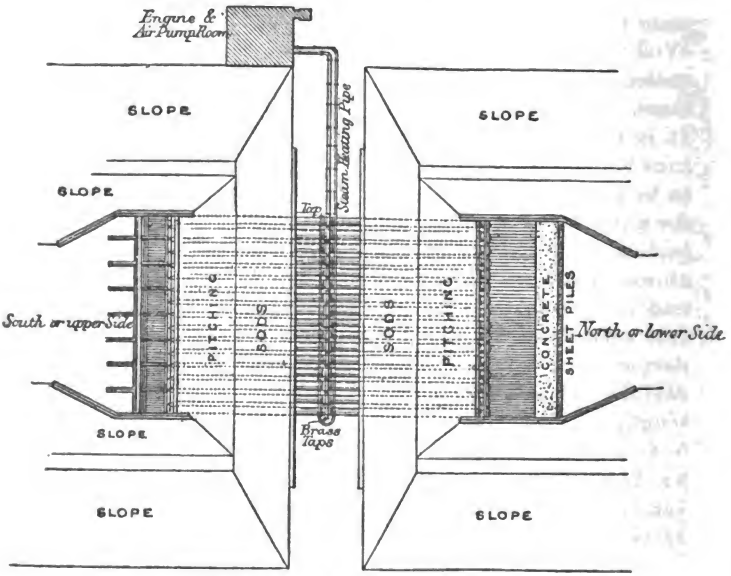

Fig. 64.—Cofferdams and Syphons, Middle Level. Plan.

these materials the side banks above the level of the ground are composed.

On the 4th May, 1862, the St. Germains Sluice gave way, the tidal waters were admitted from the river into the drain, and rushed up and rushed down again with great velocity. For a distance of 20 miles the waters ebbed and flowed. In the course of a few days, the banks were

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breached at a point about four miles above the sluice, and an area of upwards of nine square miles, or about 600 acres of land, was inundated.

Sir John Hawkshaw, who was entrusted with the work of repair, determined to construct a permanent cofferdam of pile-work across the drain, as the only structure that was likely to answer the purpose. Two rows of sheet piling, 25 feet apart, were driven across the slopes at the side of the drain, which is shown in section, Fig. 65; and the intermediate portion, across the bottom and the lower parts of the sides, consisted of pairs of whole timbers driven down, 7½ feet apart from centre to centre, and the intervening spaces were occupied by panels 7 inches thick. The dam was strongly fortified by struts and ties, and was filled with clay, sacks of gravel, and, in the centre, clunch—a hard chalk-stone. Figs. 64 and 65.

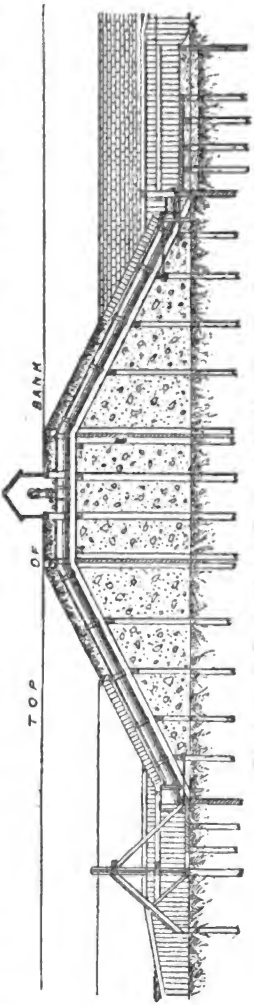

Fig. 65.—Cofferdams and Syphons, Middle Level. Section.

Sixteen syphon-pipes of cast-iron, 3½ feet in diameter, were laid across the dam for discharging the waters, at an inclination of 2 to 1 at each side. The upper portions of the syphons are horizontal, at the crown of the dam,

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and the ends also are horizontal at the bottom of the drain. The ends are laid 18 inches clear below the level of low water of spring tides, and they are consequently always under water. The top of the syphon is 20 feet above the same level. The syphons are set in action by exhausting the air from the inside, by means of an air-pump worked by a steam-engine. The air-pump has three 15-inch cylinders worked together by means of a three-throw crank-shaft, with a stroke of 18 inches. The engine is of 10 nominal horse-power, having a 12-inch cylinder with a stroke of 20 inches.

The total quantities of the several kinds of material used in the construction of the cofferdam and the syphons are as follows :—

COFFERDAM.

Timber	90,693 cubic feet.
Iron	75½ tons.
Cement	432 casks.
Clunch	2,444 tons.
Sacks	36,524 in number.

SYPHONS.—The total weight of metal-work in one syphon, exclusive of the pipes and the connections, is 36 tons, and the total weight of metal work in the sixteen syphons, including the communication and air-pipes and connections, complete in every respect, is 610 tons.

XIV.—THE WITHAM DRAINAGE.

The river Witham takes its origin near South Witham, a village about 10 miles north of Stamford; thence it flows nearly due north to Lincoln as a small stream draining the lands through which it flows. Thence it takes a south-easterly direction through a level tract of country to the sea, as shown in Fig. 66, passing on its way the town of Boston, which is called the metropolis of the Fens. The river takes the whole of the waters of the northern portion of the Lincolnshire Fens, known as the 1st, 2nd, 3rd, and 5th districts; likewise the East, West, and Wild-

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mere Fens of the 4th district, and Holland Fen. These

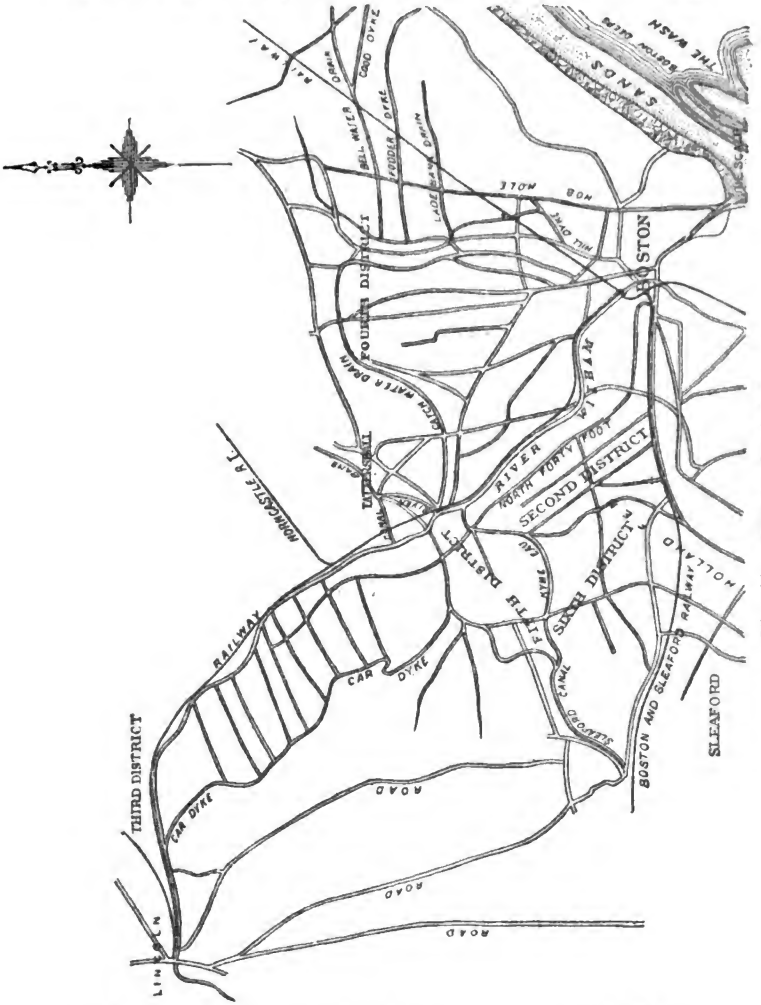

Fig. 66.—Witham Drainage.

surfaces comprise an area of about 137,000 acres of land.

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The Witham was originally a tidal river, and navigable to Lincoln, a distance of 30 miles. By neglect it became much silted up; and, as a remedy, a sluice was erected at Boston about the year 1530, under the advice of a Dutch engineer, May Hake. The sluice failed to perform what was expected of it. In 1751, Boston Haven, then a reach of the river below Boston, partially silted up, so that, though large vessels of 200 tons previously came to Boston, only sloops of 50 or 60 tons could then arrive there. The North Forty Foot was blamed for abstracting the water-supply of the river. A new sluice, called the Grand Sluice, was substituted for Hake's Sluice, and was built across the river a short distance above the town. It consisted of four arches, about 21 feet wide, one of which was used as a lock. Self-acting sea-doors were hung on the outer side of the sluice, and, in the interior, slackers or draw-doors were hung for regulating the level of the water in the river. The cost of the works amounted to £60,000. It was found, after all, that the drainage and the navigation were inconsistent with each other. The river, left to itself, silted up.

The land in the East Fen, originally the lowest in level, became lowered by the thorough drainage to the extent of from 1 to 2 feet—in some cases 2½ feet—below its original level. The upper surface of the soil, full of peat and organic matter, was saturated with water, and as the soil has, in the course of years, been worked and cultivated, the organic matter has gradually decayed. By drainage the soil has become less spongy and compressed, and therefore it has subsided from its original level. Hobhole Drain, in consequence, did not work so effectually as at first, and water, in wet seasons, was left for a considerable length of time on the lowest lands. Sir John Hawkshaw was, in 1861, consulted on the question. He proposed, by an improvement of the haven, to lower the low-water mark; or, as an alternative, to erect a sluice about the middle of the drain and a steam pumping-engine to lift the water

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from the low-level portion of the drain at the lowest lands —that is to say, at the upper section of the drain—to the level of the high-level portion. As the first alternative involved the co-operation of all the trusts concerned, the second was adopted, and pumping-machinery was, in 1870, erected at Lade Bank, a station on the upper part of Hobhole Drain.

The works comprised—(1st) a sluice or dam, having three waterways, each 12 feet wide, and as high as the dam, closed by ordinary swing-gates, in pairs. The central waterway is also used as a navigation-lock, having two pairs of gates. (2nd) Two pump-wells, each 12 feet wide, also closed by ordinary swing-gates, in pairs. The engine-house is built over the wells. (3rd) The boiler-house, with storage for coals, and the chimney adjoining. In each pump-well there is a double-suction Appold centrifugal pump, having a horizontal fan 7 feet in diameter, 2 feet 2 inches deep, on an upright shaft. On this shaft, at the upper end, a bevel pinion is keyed, which is driven by a mortice bevel wheel on the main-shaft of the steam-engine. There is a pair of engines, self-contained, on one bed-plate, to each pump. The engines are condensing, vertical, and direct-acting, with a rocking-beam parallel motion. The cylinders are 30 inches in diameter, with a stroke of 30 inches. They are worked expansively, the steam being cut off at one-fourth of the stroke; and the engines make 36 revolutions per minute. The two pairs of engines are supplied with steam from six Lancashire boilers 6½ feet in diameter, 23 feet long, having two furnace-tubes 2½ feet in diameter. The working pressure in the boiler is 45 lbs. per square inch.

The excavations, buildings, and machinery were erected in one contract by Messrs. Eastons, Amos, and Anderson, for the sum of £17,000.

The entire drainage of 35,000 acres of land is now performed by means of this machinery. It was well tested during the winter following the time of its completion, Within 36 hours, on the 7th and 8th December, 1870, there

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was a fall of rain equivalent to ·94 inch, while the total rainfall of that month was 50 per cent. in excess of that of any winter month during the previous forty years. It appeared that, whereas in January, 1867, with a rainfall of 3·32 inches, an area computed at from 10,000 to 12,000 acres was placed under water for several weeks, the whole of the district was kept perfectly clear of water in the month of December, 1870, with 5·28 inches of rainfall, by means of the new machinery.

The total working expenses for the year ending March 31, 1872, amounted to £573. For the preceding year it was £490, or from 3½d. to 4d. per acre drained. The cost of the works was at the rate of 10s. per acre, which, taking interest at 4¼ per cent., represented 5d. per acre.

STATISTICS OF WORK AT LADE BANK.

	Year ending 31st March, 1871	1872.
Average number of turns of engines per minute	36·02	38·20
Average lift . . . inches	44·77	45·00
Sum of hours worked by both pumps	794·25	980 5
Weight of water discharged tons	13,564,190	18,296,130
Coals consumed during working hours . . . . tons	328	397·25
Engine oil consumed . . gallons	25·75	20·25
Tallow consumed . . pounds	181	135
Waste used . . . pounds	135	85
Wages paid:—		
First and second drivers, yearly .	£158 12	£158 12
Boy, yearly	15 12	18 4
Firemen, 2,085½ hrs. at 3½d. per hr.	30 8	29 13
,, 2,033 ,, ,,		

In conclusion, it may be stated that a great number of engines are in use in the fens for pumping the water off the lowlands into the rivers, on lifts varying from 4 feet to 10 or 11 feet, and up to 15 or 16 feet as a maximum. The work is intermittent, as the engines are only in use during the winter and wet weather. Before the use of steam-power, which was introduced upwards of sixty years ago, drainage was effected by means of windmills. The earliest steam-engines were beam-engines of a massive character,

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working at a pressure of 5 lbs. per square inch, the steam being condensed by jet condensers. Two of the largest of these engines were at Podehale, near Spalding, used for the drainage of 30,000 acres of land in Deeping Fen: one being of 80 horse-power, the other of 60 horse-power, driving scoop-wheels 31 feet and 28 feet in diameter, and lifting together about 14,900 cubic feet per minute. The circumferential velocity of the wheels was from 5 to 6 feet per second. The next largest scoop-wheel was that on the Hundred-feet River, for the drainage of the Lilleport and Downham district in the Bedford Level. It was 50 feet in diameter, and was driven by a condensing beam-engine of 80 horse-power, raising the water an average height of 15 feet. Other engines varied according to the area of the district, some being of 8 or 10 horse-power. Scoop-wheels are now being superseded by centrifugal pumps; and for driving pumps for the drainage of land, the simplest vertical or horizontal non-condensing steam-engine, in the hands of men who know nothing of mechanical construction, is preferable to rotative condensing steam-engines.

XV.—Drainage in the Valley of the Po.

The valley of the Po, the most extensively irrigated district in the world, is remarkable for the excellence of the drainage works executed in recent years. In less than thirty years, from 1850 to 1879, upwards of 600,000 acres of marshy land, in the provinces of Venetia and Emilia alone, have been drained and transformed into rich country. The long lines of chimneys bordering the Canal Bianco, belonging to steam elevating machinery, remind one of a district in Lancashire. The question of drainage has from all time occupied the attention of the population of these Adriatic districts; but, in consequence of the difficulty and, more often, the impossibility, of drainage, by natural flow, it is only since the advent of steam that the work of drainage has been thoroughly performed.

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Drainage by machinery in the valley of the Po is almost entirely carried out on one uniform plan. The ground to be drained is fenced round by catch-water trenches or canals, and occasionally, when it is necessary to prevent infiltration, the bottom of the canal is deeply trenched and filled with clay. Within the circumscribed territory, a system of drains is cut, in which the water is conducted to the lowest level at a point conveniently selected, where the elevator is erected. By the elevator, the water is lifted into a canal or a river, in which it is carried off by gravitation. The elevators have to deal with variable volumes of water at variable heights; but, in general, the greater the height the less is the quantity to be lifted, so that the work to be done is in some sort constant. The heights vary generally as 1 to 3.

Three systems of machines exclusively are employed as elevators: centrifugal pumps, turbines (*rouets*, Fig. 67), and lifting-wheels (*roues élévatoires*). All of these machines are moved by steam-power, and they are the most economical. Piston-pumps, employed to raise large quantities of water through small heights, have shown not more than 35 per cent. of efficiency. Centrifugal pumps are of great variety of form, differing principally in the shape of the blade. The turbine is only a centrifugal pump on a vertical axis, of which the pipes are replaced by the sides of a well. It consists essentially of a circular crownplate, having a central opening equal to that left by the crownplate. The wheel is placed low enough to be submerged at all levels of the water. It is driven by toothed gearing or by bands. The difference between the turbine (*rouet*) and the centrifugal pump is that the passages for water are much larger in the first than in the second. Consequently, the velocity of the water is less and occasions less friction, whilst the water escapes more freely. For small quantities of water, the pumps are more economical than the turbines, as the cost of construction of wells is saved. The turbines adapt themselves to great variations of level, whilst maintaining

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a high ratio of efficiency, about 75 per cent. Speed is, according to one system, altered by means of changes of toothed-wheel gearing to suit the various levels. According to another system, the speed is maintained constant for different levels, but the efficiency may fall as low as 60 per cent.

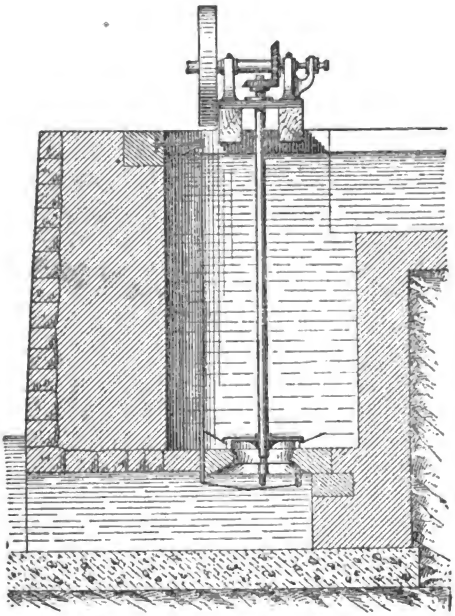

Fig. 67.—Turbine, Po Valley.

For this reason, centrifugal pumps and turbines are, in the Po valley, being gradually replaced by lifting-wheels, Fig. 68. These wheels are arranged like undershot water-wheels, but with the reverse action, that the water is raised by the wheel. Originally, the blades or floats were straight and radial, and the wheels were of low efficiency—about 30 per cent. They dashed the water about as each blade entered it; whence their Italian name of *ruote a schiaffo*

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(literally, slapping-wheels). The blades are now inclined at about 60° to the radius, and are formed with a double curvature, so that the water is lifted without agitation or useless elevation; and by means of a sliding iron shutter, the opening for the access of water to the wheel is formed at the lower part only. The efficiency is increased as the difference of levels is increased, and it averages 80 per cent. The wheels manufactured by Mr. Zangilorami are constructed entirely of iron, and some of them are made as much as 39 feet in diameter. The side walls are exactly dressed with a clearance off the wheels not exceeding one centimeter, or four-tenths of an inch. The minimum immersion is 20 inches for wheel of 26 feet. The circumferential velocity is constant, about 57 inches per second.*

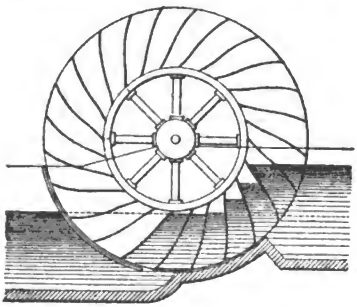

Fig. 68.—Lifting Wheel, Po Val

XVI.—Drainage of Peat Bogs in Ireland.

The reclamation of the extensive peat bogs of Ireland has become matter of general interest, and specially to practical agriculturists. The growth of peat has been ascribed to various causes, amongst which the destruction of forests, by interrupting the drainage of the country and causing stagnation of water, and the consequent growth of aquatic vegetable matter, is the most generally received opinion. The growing surface of bogs is, in fact, composed of a distinct predominant moss, the *sphagnum palustre*,

* See a full account of this dr ining machinery in the "Bulletin de a Société d'Encouragement," 1885, page 266.

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or bog moss. It grows in a state of activity varying according as water is more or less abundantly supplied to its roots. It is to the successive growth and decay of the moss that the enormous accumulation of vegetable matter in bogs is to be attributed.

The wettest part of all bogs is about the centre, which is most remote from drainage. The surface rises gradually towards the middle, as there the sphagnum grows in the greatest luxuriance, the surface being either covered with water, or in a semi-fluid state. The quantity of water held by the moss or detained in the peat forms a large proportion of the whole bulk. Messrs. Mullins mention some striking instances of the contraction of peat deposits when penetrated and drained. The Edenderry and the Ballinasloe bogs, through which the Grand Canal of Ireland passes, sank 43 feet and 20 feet respectively when cut through, insomuch that parts of the route shown in section on the plans as deep cuttings had ultimately to be embanked. The Edenderry bog lies in a basin, the bottom of which is many feet below the adjacent river, which had been at one time the site of a lake. The Ballinasloe bog extends for a distance of 12 miles between Shannon Harbour and Ballinasloe. This district had been no doubt the site of a deep lake formed by large rivers in the vicinity.

The sources whence bogs derive the water which enters into their composition and perpetuates their growth are twofold: namely, internal springs issuing from the subsoil on which they rest, and the rains that fall upon their surfaces. Correspondingly, the system of drainage is twofold, acting on the top and acting on the bottom. To effect this object, the original outlets of the bog must be ascertained, which is easily done by taking levels over the surface of the bog intended to be drained, and noting the depth at each station. Duly plotting the data thus obtained, it is generally found that the natural outlets are in the lowest situations, and are easily converted into tap-drains,

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by removing all obstructions in them, and making a sufficient fall by sinking to the necessary depth. If it be found that such outlets do not command the drainage of the undermost strata of peat, new drains may be formed at lower levels, these taps being brought up to the verge of the bog; whilst, as far as practicable, main discharging drains should be sunk leading towards the taps, if the bog be of sufficient solidity to admit of their being kept open. If the moss be wet and deep, it is useless to attempt the making of a main drain in the first instance, unless where a stream running through a bog admits of sinking to the gravel. Where main drains are impracticable, surface drains, which are to be resorted to in all cases, should be made in number and direction proportionate to the extent and degree of fluidity of the body, leading in the direction of the fall of the surface to the outlets. Such drains may be opened about 5 feet wide at the top, 1 foot at the bottom, and sunk to the depth of 3 feet, if the moss be sufficiently firm to admit of their being made to these dimensions. If not, a less breadth and depth will suffice in the first instance; and by subsequent operations, as drainage proceeds, they may be sunk to the specified depth and breadth. While subsidence continues, by which the depth of the drains in relation to the surface will be diminished, they should be kept to the given sizes by repeated widenings and sinkings. When consolidation has in a degree taken place, some of the surface drains may be gradually widened and sunk to a greater depth, to act as main conductors into the principal natural outlets, which are always near the verge or lower edge of the bog.

In constructing the Ballinasloe Canal, for instance, operations were commenced by making a drain in the centre-line of the canal through its entire length, 5 feet wide. As shown in Fig. 69, parallel drains of like dimensions, A A, were made at each side, 30 feet from the centre, which lined out the limits of the top opening of the canal, allowing a slope of 9 inches to the foot, assuming that the subsi-

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dence of the bog would increase the slopes to 18 inches to the foot. At 4 perches and at 10 perches from the centre, on each side, parallel drains, B, B, and C, C, were made of like dimensions, making seven drains in all. These were crossed by drains at right angles.

When bog is found sufficiently firm to allow main discharging drains to be sunk in the first instance, these should be made in the required number to discharge into

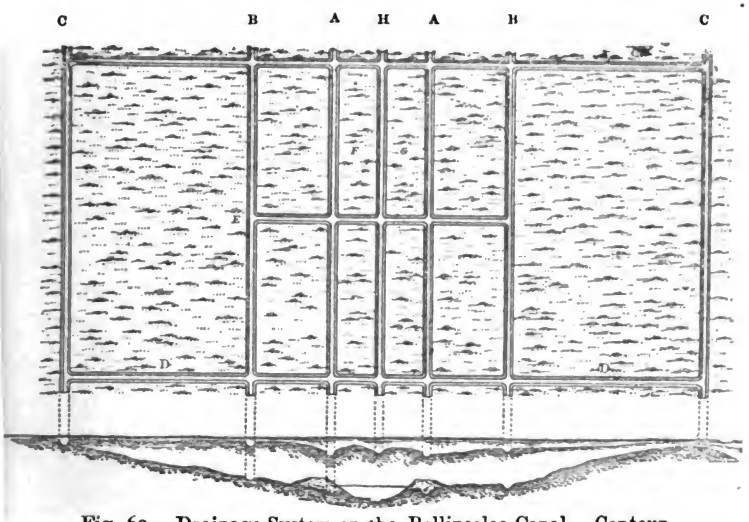

Fig. 69.—Drainage System on the Ballinasloe Canal. Contour Sections showing Subsidences.

the natural outlets. The surface drains should then lead at right angles into the main drains. The sides of the drains require a greater or less degree of slope, to prevent collapse, according to the degree of humidity of the bog. In comparatively dry peat, the sides may be cut nearly vertical without risk of their falling in. If desired, some of the main drains may be made navigable at a trifling cost, for small boats, to carry clay and other manure from the upland, and to facilitate other agricultural operations.

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Some bogs may be effectually drained in the course of a year or two; others may require four or five years, or even a longer period. The work of drainage should be carried on gradually, allowing time for the consolidation of the surface. When the bog becomes sufficiently consolidated to bear the weight of carts and horses in dry weather, the next process is to level the irregularities of the surface for cultivation, and to fill up the smaller drains with a covering or top dressing of limestone gravel, mixed with clay or marl, if found beneath. The peat will, in the course of a year or two, be converted, for some inches in depth, into black mould.

The perfect drainage of a deep red bog, the drainage of the whole mass of peat down to the substratum on which it rests, is a problem of a different kind. Mr. T. J. Mulvany describes the method employed for the drainage of the Mantua turloughs, in the County Roscommon, Fig. 70. The principal work was the formation of a cut, varying from 20 feet to 30 feet in depth, nearly one mile in length, through one of the wettest bogs in the county. In conjunction with the formation of this deep cut, the complete drainage of the bog on both sides of the cut has been effected to the extent of upwards of 300 acres.

The bog cut constitutes a part of the works of the drainage district of Lough Gara and Mantua, promoted by the Commissioners of Public Works. The immediate object of the cut was to relieve from inundation the turloughs of Mantua, comprising about 700 acres of fine land, which was so circumstanced as to be liable, at certain periods, to be covered with water to a depth of from 8 to 10 feet over the greater portion of its surface, and in some places 16 feet or 18 feet. The turloughs or water hollows are about three miles west of Elphin, and at the rear of Mantua demesne, from which they take their name.

The cavernous limestone formation of a considerable portion of the County Roscommon, gives origin to a number of turloughs like those of Mantua, where there are exten-

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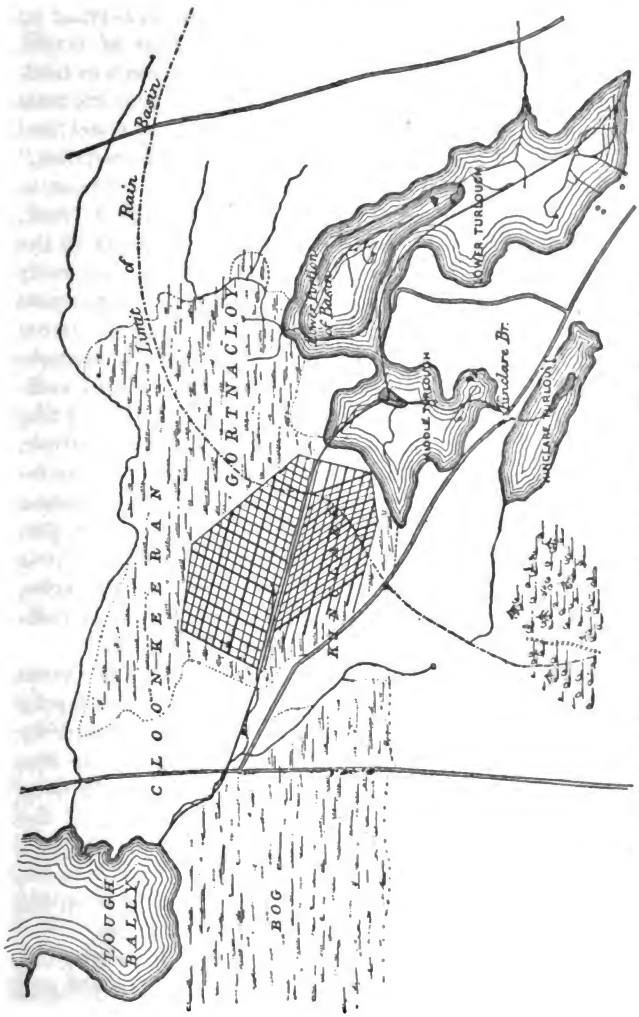

Fig. 70.—The Mantua Turloughs, and the Deep Cut through Kinclare Bog.

sive tracts of high tableland, the surface of which is undu-

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lating, and is covered with a shallow porous soil lying on the limestone rock, as, for instance, the plains of Boyle, and the Hill Rathcroghan. There are no streams or leading drains in those districts. The rainwater which falls on them is absorbed at once through the porous soil and the fissures of the rock, or sinks into "swallow-holes," which are frequent on the surface, and which appear to lead into extensive cavities within the mass of the rock, whence it is discharged as springs round the verge of the tableland. The streams from these springs frequently flow into some low basin, from which there is no overground course by which the water can pass off, but in the bottom of which there may be one or more subterranean passages or swallow-holes, which during the summer afford sufficient means of discharge for rainfall as well as for spring water. But when there is a continuance of wet weather, those passages are generally insufficient to carry off the increased supply from the springs and the rainfall drainage. The water consequently rises and covers the lower portions of the lands, and it continues to rise until it finds vent at the lowest point of the verge of the turloughs, or until the discharge through the swallow-holes is sufficiently accelerated by the head of water over them.

Turloughs which owe their origin only to these causes may be drained either by cutting off the principal supply from the swallow-holes, which may be accomplished by altering the course of the stream before it enters the turlough; or carrying it in a contour course round the deep part of the turlough, and across the lowest point of the ridge which bounds it; or else by making a cut through the ridge at that part, to such a depth as to secure the perfect drainage of the turlough at all times. A deep cut of this description is preferable to a contour course.

The turloughs of Mantua are at the northern verge of a tract of high tableland at a level of from 350 to 500 feet above the level of the sea, extending for a length of ten miles, from Elphin to Ballintobber, and for a breadth of

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from four to five miles, between Tulsk and Ballinagar. There are no rivers or streams to carry off the drainage water, and the great quantity of water which falls on this surface in time of rain is received directly into the fissures of the rock which forms the substratum, and collected in caverns, whence the springs are supplied which abound along the verge of the district in every direction. The turloughs are divided into three portions by ridges of comparatively high land, which separate their waters, except when in a state of high flood. The lower, or eastern turlough, is the largest and deepest; the middle turlough is the next in extent and depth; and the southern, or Kinclare turlough, is the smallest, and is connected with the middle turlough by means of a small artificial cut. At full flood an extensive lake is formed, varying in depth from 10 feet to 18 feet, and the quantity of land covered is nearly 700 acres. After the turloughs become once filled with water, the subterranean passages require a long time to carry it off; and when the basin is nearly emptied one or two days of heavy rain are sufficient to raise the water to a high level again. It thus happens that the lowlands are generally covered for eight or nine months in each year.

The cut through the bog is 30 feet below the original surface of the bog at its summit, so as to insure the complete drainage of the middle and southern turloughs through it. It was not considered necessary to make the cut as deep as the lowest part of the eastern turlough, because the streams which flow into it are taken up at such a level as will admit of their being carried in a contour course round the very deep part, and through the ridge which separates the eastern and middle turloughs into the new cut at its intended level. Any rain that falls immediately on the low part of the eastern turlough is easily carried off by the swallow-holes.

The line of the cut through the bog follows the general direction of the stream to Lough Bally, in a straight line. Upwards, it curves from the summit of the bog into the

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middle turlough. The total length of the line, from Lough Bally to the small pool in the middle turlough, called Carrigeen Lough, is very nearly two miles. Three-quarters of a mile of this length from Lough Bally, and a quarter of a mile next the turlough, run in from 8 to 10 feet of cutting through firm peat, with a substratum of limestone, gravel, and clay. The central portion, one mile in length, passes through the bog in from 20 feet to 30 feet of cutting, as before stated, below the original surface. The sides of the cut are formed with slopes of 1 to 2 in the consolidated bog, and 1 to 1 in the clay and gravel.

In the operation of draining the bog on each side of the cut, a drain was first formed in the centre line of the deep cut, and two others parallel to it, 20 feet distant on each side, Fig. 71. Similar parallel drains also were sunk at distances of 10 perches apart, on each side of the cut, to the extent of the bog proposed to be drained; and cross-drains, at the same distance, leading into the centre cut, to which they were inclined at such an angle as best suited the natural inclination of the surface of the bog. The area was thus cut up into portions of 100 square perches. The surface-drains were made 3 feet wide at the top, 18 inches at the bottom, and 3 feet deep. Near the centre of the bog, where it was wettest, the drains could only be opened to very small dimensions at first, and then constantly worked on and gradually enlarged as the surface became consolidated.

When all these surface-drains had been opened, the three drains on the line of the proposed cut were enlarged to a breadth of 6 feet at the top, 2 feet at the bottom, and 4 feet deep. Every second parallel and cross-drain on each side of the cut was then enlarged to the same dimensions, care being taken to keep the centre drains constantly cleared, and in enlarging the cross-drains to work from the centre towards the bog, till the drainage water was thus led to the centre drains, when it was kept flowing

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in very considerable quantity. The central and two side-drains, and the portion of the cross-drains leading immediately into them, were constantly worked on and deepened according as the gradual consolidation of the surface would permit, in order to secure the greatest possible subsidence in the line of the main cut. When it was required

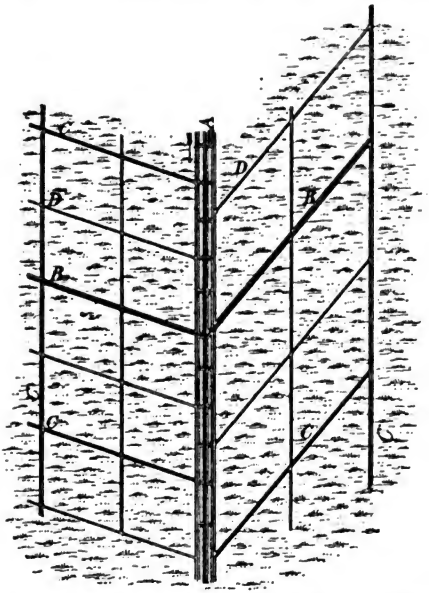

Fig. 71.—Drainage of Bog in the District of Lough Gara and Mantua, Roscommon.
A, Drains in centre line of new cut. B, B, Main Drains. C, C, Minor Drains. D, D, Surface Drains.

to deepen the central drains, the drainage water was turned down the side drains, the central drain was cleared and deepened, the water turned into it, and the two side drains sunk to the same depth. The spoil from these three drains was placed on the banks between them, and small cross cuts were made from one side drain to the other, at

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distances of 5 perches, along the length of the cut, in order to promote the consolidation of the intermediate banks of peat.

The drains just described were made in the later months of 1846, and the surface of the bog was left to drain during the winter, without any further enlargement of the drains. They were merely kept clear to ensure efficient action. Small cuts were also made from any swampy places in the surface of the bogs to the nearest drain, so as to prevent as much as possible any water lying on the surface. Meantime, the solid peat and gravel in the line of cut were excavated between Lough Bally and the wet portion of the bog, and also in the solid portion of the cut near the turlough. When the portions of peat between the centre and the two side drains were sufficiently consolidated, they were excavated to the level of the bottom of the centre drain, and wheeled into spoil outside the side drains. The central drain was then sunk as deep as the state of the material would admit of, and kept constantly cleared until the peat was sufficiently consolidated to admit of another lift being taken off.

In April, 1847, operations were commenced for enlarging the parallel drains 40 perches asunder, and some cross drains, to act as permanent main drains. They were made from 6 feet to 7 feet wide at the top, and only 6 inches wide at the bottom, and from 6 feet to 7 feet in depth. They were made so narrow as a preventive against the rising of the bottom.

By those main drains the surface was divided into parallelograms of 10 acres in extent, which were subdivided by the minor drains into portions of $2\frac{1}{2}$ acres, and still further divided by the surface drains into lots of 100 square perches. The drains are represented on the map, Fig. 70: the surface drains by faint lines, the minor drains by strong lines, and the main drains by double lines.

Since the commencement of the works on the cut, the

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surface of the bog gradually subsided to a considerable degree, particularly in the line of the main cut. At the close of the year 1846, it had sunk 3 feet 10 inches at the summit of the bog, and in September, 1847, it had subsided 10 feet 6 inches. At a later period it had sunk from 14 feet to 16 feet.

XVII.—Draining of Desert Land in the South of France.

In the West of France, near Bordeaux, there existed previously to the year 1850, an immense territory of desert land, comprising nearly 2,000,000 acres, designated "Les Landes de Gascogne." The territory is triangular in shape, extending along the shores of the Bay of Biscay for a distance of 140 miles, and parallel to the course of the river Gironde, for a distance of 120 miles from the mouth of the river.

The desert is a vast and nearly horizontal plain, at an average level of 330 feet above the level of the sea. The surface is poor sandy soil, of from 12 inches to 20 inches in depth. Under the surface soil, there is an impermeable layer of silicious sand, agglomerated by vegetable matter, varying in thickness from 16 inches to 20 inches, and forming a sort of organic cement, which is known in the country by the name of "alios." Beneath the alios is a substratum of compact white sand impregnated with water. There is no trace of water on the surface in summer; but during winter, previous to the execution of the drainage works, the abundant rain of that coast, experienced for more than six months, falling on the plain, could neither flow off the surface nor percolate sufficiently through the impermeable layer of alios. The water remained stagnant until it was evaporated by the heat of the summer.

From the results of exact surveys, it appeared that the average inclination of the ground was about 1 in 1,000, but that in many parts it does not exceed 1 in 2,000. It

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was shown that, upon the whole extent of the apparently horizontal plain, there exists from the summit towards the valleys exceedingly regular slopes, but so gentle that the least irregularities of the ground hinder the water from following the normal declivities. The small irregularities on the surface, which hinder the flow of the water, are never more than from 12 inches to 16 inches above or below the normal slopes of the plain. It follows that a drain from 20 inches to 24 inches deep, having the bottom parallel to the general slope of the ground, could be made along its whole length, without necessitating a cutting of more than from 24 inches to 28 inches, in order to allow the water from rainfall to pass perfectly away. Moreover, a ditch extending along such sandy permeable ground, will drain the surface to a considerable distance on each side of it; and as its average inclination would be about 1 in 1,000, the water would percolate slowly and regularly to it without causing injury to the sides. In consequence of the permeability of the surface soil very few drains are required.

It was decided to make a trial. A superficial area was selected of about 1,250 acres of the desert, nearly on the summit, and in the middle of one of the most sterile parts, being in every sense under the most unfavourable conditions for draining the soil. At the time of commencing operations the ground was covered with stagnant water, so that it was necessary to move about on the stilts used in the country. The effect of the drains was immediate; the ground was so well drained that during the heaviest winter rain no stagnant water existed on it, and the water flowed away abundantly and regularly. The rain water immediately percolated through the soil into the drains, and was never noticed to flow along the surface. Although it is over thirty-five years since these drains were executed, yet such is the slowness and regularity with which the water percolates into and along them, that they have not silted up nor have their sides been injured.

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Shortly after this trial ground was drained, it was sown with fir-seeds and acorns, and the result was so satisfactory that in the following year numerous proprietors of portions of the desert carried out similar works, and with equal success. In less than five years more than 50,000 acres has been drained and cultivated for forests. In five years from the first sowing on the trial ground, fir and oak-trees had grown over the whole area to a height of nearly 12 feet, and each tree was about 12 inches in circumference above the ground.

In virtue of special legislation, a general plan was prepared for draining the waste lands belonging to the communes, comprising about 720,000 acres, irrespective of 364,000 acres belonging to private individuals, which remained to be drained. The plan comprised the execution of the principal canals necessary for receiving and carrying away the water flowing from the land drains. For this purpose, the whole country had to be again carefully levelled, showing that the inclination of some portions of the plain was not more than 1 in 2,000. The main canals in the department of La Gironde were from 13 feet to 16·4 feet wide at the bottom, and their total lengths amounted to 1,365 miles. The canal between the pools or lakes Lacanan and Langourarde, bordering the sand dunes on the coast, is 39·4 feet wide at the bottom, 6¼ miles in length, and has an inclination of 1 in 4,000; and the canal made between the lakes d'Hourtuis and Lacanan, through the middle of a marsh, for a distance of 5¼ miles, is 23 feet wide at the bottom. These two canals receive the drainage water of 200,000 acres of surface.

In 1865 the drainage works of the communal lands were completed at a cost of 1s. 10d. per acre drained.

With the exception of lands in dispute, the whole area is now under forest cultivation, consisting mainly of fir-trees, with oak-trees to a limited extent. The results are highly satisfactory.

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DIVISION II.

DRAINAGE OF TOWNS AND BUILDINGS.

SECTION I.

Refuse Matter.—Classification of Sites.—Levels.

THE refuse matters to be discharged from towns and buildings—consisting of the disintegrated materials of street paving and roads; of superfluous rain-water; of excrementitious matters, solid and liquid; of the waste products of combustion; of the refuse of animal and vegetable substances; besides the various waste matters used in manufactures—require arrangements of different kinds to be provided with regard to the purposes to which these matters may be usefully applied. For such discharges of these matters as are to take place through subterranean channels, one principle is, however, common to all, viz. that the receptacle to which they are conducted must be situated at a level somewhat lower than that from which they are forwarded. The arrangements for this purpose will, therefore, be varied according to the nature of the site of the town. If this be low in relation to the surrounding country, and level, the refuse may be indifferently collected within or without the town; with, however, the advantage in the latter plan of avoiding such exposure of the decomposed matters as tends to pollute the atmosphere, and at the same time saving distance in the transfer of such portions of those matters as are destined for agricultural uses. If the site of the town be a valley with

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lower ground in the midst of it than is found anywhere without its limits, the readiest point of collection will be the lowest level in the town itself at which the drainage can be united, and artificial power will be required to distribute such matters as are intended for agricultural purposes around the higher ground outside. From towns which occupy elevated sites, having lower lands around them, the refuse matters and drainage waters should be conducted away at once; or, if found necessary to collect them, a point or points should be selected for this purpose altogether beyond the limits of the town itself.

In the several cases here supposed, the question of disposing of the refuse matters should be treated without any reference whatever to the presence of a river through or contiguous to the town, except upon the single consideration that such river, being in all probability situated at the lowest level of the site, may afford facilities, after the refuse has been collected in reservoirs near its banks, for its conveyance in suitable barges or vessels towards the higher lands for which some portion of this refuse is ultimately destined. Former practice in the art of town-draining has indeed regarded the one question of river or no river, as the grand determinal one for the disposal of drainage and refuse matters. How to get rid of the animal ordure created within the walls of a town, was formerly deemed to be satisfactorily answered provided a river flowed beneath, and offered a tide to wash away in boundless wastefulness those matters which, properly applied, will endow barren land with the richest fertility.

From the principles here laid down, it will be understood that in the twofold purposes of the drainage of towns, viz. the supply of water, and the discharge and disposal of the refuse matters, the relative levels of the town, with the adjacent districts, and of the several portions of the town with each other, are the main considerations upon which the peculiar methods to be adopted in each case are determinable; but it will also be evident that, generally, those

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surfaces which are the most favourable for an economical water supply are the least so for the ready disposal of refuse matters, and the converse is equally true.

Thus the flat districts on the margins of rivers and inland streams of adequate capacity are the most favourable sites for towns for the supply of water, but for drainage they are the least so; since the main channels or sewers are required to be laid at low levels, and the raising of their contents for use upon the neighbouring lands, which are probably much higher, becomes a very expensive process. On the other hand, a town on a hill-top is the most readily and cheaply drained;* but its supply with water, whether from springs, rivers, or surface drainage—all at lower levels—is a work of great and constant cost.

Let us consider the several kinds of site which towns may occupy.

First.—A plain or flat surface, with surrounding country of similar character. Water from rivers, springs, or from the surface of lands in the neighbourhood. Artificial power will be probably required to raise the water however derived. The drainage matters must be conducted into one or more main sewers, and raised by artificial power for dispersion.

Second.—A plain or flat surface, with surrounding country rising from the town. Unless well situated with regard to a river, the supply of water will probably be the most economically obtained from springs on the hills, or from the collection of the waters which accumulate upon their surface. The drainage matters, if destined for the higher lands, should be generally conducted by mains towards the outskirts of the town, and the question of levels will evidently derive additional importance from the necessity of raising the sewage to levels naturally above that of the town itself.

Third.—A plain or flat surface, with surrounding country

* With the qualification that ventilation of sewers be amply provided for.—[EDITOR.]

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falling from the town. The supply of water, beyond that derived from wells and springs, will require artificial power, while the drainage matters may be collected in main sewers, and, in all probability, dispersed without any application of power, by the force of their own gravity.

Fourth.—An inclined surface on the side of a hill. Water will be derivable, probably, from several sources. If a river flow at the base of the site, the lower parts of the town will be most economically supplied from it, while for the higher the surface water from lands above or springs will be the most readily available. The general system of collecting and distributing the drainage matters will be chiefly dependent upon the localities where they are intended to be ultimately disposed of. If these be on the lower part of the hill, the method will be very simple, requiring only that main sewers be laid at the base of the town, from which the sewage may be distributed without any application of artificial power. But if the disposal of the sewage be inevitably desired on the lands above the town, the site constitutes one of the least favourable for economical drainage, which will require a constant expenditure of artificial power.

A river-valley and a hill-top will evidently present a repetition or duplication of similar features to those here described, the only limitation in the resemblance being that, in the case of a town on the summit of a hill, the water supply will, most probably, be derivable only from lower sources by artificial power.

In these sketches the general superficial features of the site are of course only referred to. Intermediate undulations which may exist will affect the determination of the details of any arrangement of channels designed for serving the drainage of the town.

With reference to the artificial power which may be required for the supply of water, or the discharge of the drainage matters, if a tidal river can be commanded, it becomes a question of the highest importance whether this

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cannot be, and, if so, in what way, made available as a source of the power required. And another question deserving the most attentive consideration is, whether the ebb-tide may not be rendered efficient in aiding the discharge of the sewage where the fall is inadequate to insure its self-discharge.

As a general principle in town drainage, however, it should be so arranged and conducted as to require no artificial supply of water. The surface water should always be made sufficient to carry away all refuse matters, solid as well as liquid. Two reasons exist for this; first the economy of the water, which in many cases is a paramount, and in all should be a leading, consideration; and, secondly, the dilution of the sewage with any unnecessary liquid involves more capacious arrangements for its diffusion, and in most instances an extravagant amount of power to raise it.

The utmost economy of water for draining purposes can be secured only when a sufficient inclination in the sewers can be obtained. The methods of making a fall the most effectual are, therefore, deserving of the most careful attention in every scheme for town drainage. The application of the tidal waters for assisting the discharge of the sewage can consequently be entertained only with reference to the principal main sewers at the lowest level, and with such adaption, if practicable, as will admit the subsequent separation of the proper sewage matters from the water thus introduced to aid their progress and discharge.

Without seeking records of the actual levels of any one of our river-watered towns, we may assume as a feature common to many of them the existence of several ranges of elevation, running parallel, or nearly so, to the direction of the river, which we will suppose to be generally east and west. These ranges of elevation will be interrupted at intervals by ancient watercourses, and also by small ridges running north and south. These several features of the natural surface will determine the most economical courses

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for the general system of drainage. Thus the highest of the ranges, which we will call A, as in the sketch, Fig. 72, should have a course of sewers for the especial service of the districts above it; the next range (B) should have another course of sewers to serve the district between A and B; the

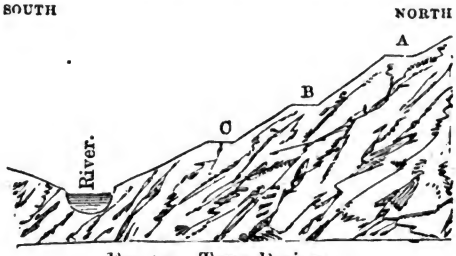

Fig. 72.—Town Drainage.

following range (C) should similarly be provided with its course of sewers to drain the district between B and C, and so on. The general inclination, east and west, of each of these courses of sewers would be determined by the position of the ridges and hollows running north and south, as shown

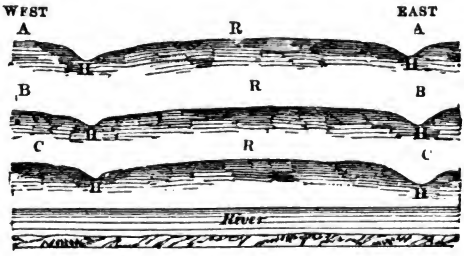

Fig. 73.—Town Drainage.

in Figs. 72, 73, where the highest points of the several courses would be at R, and the lowest at H successively. By this arrangement, means would be obtained of collecting the sewage at each level or range of elevation, and disposing of it with the minimum power to be expended in raising it for manuring purposes.

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The next great question to be determined would be the most economical power that could be obtained at each of these points, H, for the purpose of raising the sewage for dispersion upon the land. For the lower level or range, the pumps could be worked by wheels driven by the tide of the river-water; and, in all probability, those for the upper levels could be worked, at any rate partially, by streams of water conducted, in suitable channels, from the uplands. At least, while we can command the immense water-power of rivers, and of the accumulated surface drainage from the large districts above, the best means of making this available for our purpose deserve all consideration, before we resort to the expensive power of steam. For the extended flat districts of towns which bound tidal rivers, the tides of the river could also be made available, to a great extent, in doing the work required. The completion of the scheme would then want the details of the arrangements to be made suitable to the superficial features and relative levels of each part of the site for the construction, &c., of the sewers, and the machinery to be applied for raising and distributing the sewage; and we should finally be prepared to arrange the minor channels or drains so as to subserve the efficient cleansing of every inch of the surface, and of every individual tenement in the town.

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SECTION II.

Width and Direction of Roads and Streets.—Substructure and Surface.—Paving and Street Cleansing.

The drainage and cleansing of the roads, streets, and thoroughfares of a town are acknowledged to be public purposes of the highest utility. The facility of effecting these purposes is dependent upon the several circumstances of the dimension and situation, and the sub- and superstructure of the thoroughfares. The width of the streets is influential in admitting or preventing the access of air and winds, by which the wholesomeness of their condition is largely affected; and also in rendering the process of cleansing by hand or other labour easy or difficult. The direction of roads and streets—vertically in their relative levels and inclinations, and, laterally, in their coincidence with or opposition to the courses of the prevalent winds—is a condition of great importance in affecting the facility and economy of the processes of drainage and cleansing. And the relative dampness and dryness and quantity of débris produced upon any public thoroughfare are mainly attributable to its construction in the subsoil, and superficial formation.

Courts and narrow passages, such as abound in most towns—relics of public ignorance and private cupidity, destined to be destroyed in the progress of enlightened sanitary reformation—limited in width and bounded by elevated buildings, never receive their due share of light, air, or water, and thus present the greatest combination of difficulties to the vital processes of drainage and cleansing. And these purposes can never be economically and efficiently fulfilled until a minimum of width and a maximum

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of height of buildings are recognised as the elements of street proportion. The recorded and repeated evidence on this point is more than enough to establish the general principle, although the precision of the details requires observations of a more exact nature than have yet been made. It is certain, however, that no street should be less in width than the height of the buildings on either side of it —that is, that the angle formed by the transverse surface of the street, with a line from its extremity on one side to the summit of the buildings on the other, should never exceed 45°. And in proportion as this angle can be reduced will be the facility afforded for the desirable operation of the air and of such rain as may fall.

Provided this principle be strictly observed, the comparative declivity of the surface will become of minor importance. Certainly, the greater the declivity the more rapid and effective will be the action of rains in cleansing and washing down the débris upon the surface of the street; but it should be the peculiar province of the subterranean sewers constructed beneath to compensate for the relative flatness of the surface, by affording a channel of artificial declivity, that shall at all times free the surface from these matters as quickly and effectually as possible.

Connected with the subject of road drainage as applicable in the suburban parts of a town, the necessity of providing covered drains cannot be too rigorously enforced. Open road ditches are known to become receptacles for filth and refuse matters of various kinds, and the trouble and expense of cleansing and keeping them in repair, involving a constant making-up of the banks and clearing of the beds, are commonly evaded by a total neglect, which leads to a stoppage of the channel and a constant exposure of decomposing matters, both offensive to the senses and injurious to health. These roadside ditches are frequently, moreover, adopted as the only available channels for dispersing the sewage of the suburban building; and being

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thus converted into open sewers with little or no attempt at formation, and very little care in preserving even their original rude form and capacity, the evils of retaining them are multiplied to a degree actually dangerous to the health of the inhabitants and of passengers.

Added to the inefficiency of open road drains or ditches is the waste of surface which they involve. Pedestrians in the suburbs of towns know well that of a narrow road, nearly one-half the width is frequently occupied by a wide and sluggish ditch, and that, in the absence of any raised footpath, they are frequently driven to a dangerous proximity to its foulness in order to escape destruction by the heedless and perhaps drunken drivers of vehicles. If these ditches were covered and converted into active sewers by the use of pipe-tiles, of comparatively small and yet ample dimensions, space would be afforded for the formation of convenient footpaths on which a walk would become a luxury instead of being a task of danger and annoyance. Those who have "picked their way" along the unpavemented strados of Rome, and contrasted them with the easy security of some of the similarly narrow streets of our own metropolis, will readily appreciate the value of the change which might be thus cheaply effected in our suburban roadways.

The quantity of surface wasted by the open road ditches, and the corresponding area thus exposed for the evaporation of stagnant moisture, may be readily calculated from the dimensions of the ditch. It may be safely assumed that for each mile of road, at least half an acre of surface is thus, on an average, misapplied.

The position of the main sewers of a town being beneath and in the same direction as its streets, these afford the proper channels for discharging the waste water and all other matters from the surface of the streets. This doctrine is liable to be challenged by all those practical economists who contend that street débris is so injurious in its admixture with the excrementitious matters flowing from

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a town, that it should be scrupulously kept separate, and periodically removed by hand and horse labour above ground. But if we take into the account, on one hand, the small proportion which the solid part of this débris bears to the total of solid and liquid excrements, house refuse, street drainage, waters, &c., which are universally allowed to be the proper subjects of sewer discharge, and, on the other, form a due estimate of the inconvenience, expense, and disgusting annoyance of removing this street refuse by any expedient above ground, the result of the calculation will lead, we think, irresistibly to the conviction that the whole of these matters should be by the readiest possible methods delivered into the sewers, and by them conveyed at once to receptacles suitable for their collection and treatment.

The exact proportion between the solid street refuse and the total of house-sewage and street-drainage (which may be supposed to find its way unavoidably into the sewers) is difficult to determine with any certainty approaching to exactness, but an approximate estimate may be formed from such materials as we can command. The excrementitious matters produced by each individual are generally considered to amount to an annual quantity equal to one ton in weight, and the other matters which are comprised in the total of house-sewage and street-drainage may be supposed equal to a similar quantity. We have thus a total equal to two tons annually per head of the population. Now, in the township of Manchester, of which the population in 1841 was 164,000, the number of yards of street surface swept in the same year was 21,500,000, and the number of loads of these sweepings removed equalled 25,029, each of which is equal to a weight of one ton. Assuming the proportion between the population and street-surface of this township to be a fair average for most towns, we have thus a total of house-sewage and street-drainage equal to $164{,}000 \times 2 = 328{,}000$ tons, being $\frac{1}{13}$th of the former, or less than 7·7 per cent. This rough calculation

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will be quite sufficient to show the small proportion in which the manurial value of the sewage is liable to be injured by the admixture with it of the street débris in the common receptacles or sewers, and the consequent inadvisability of engaging in the expensive operations of carting and removing this débris by any combination of human and animal labour.

The amount of street débris, or the quantity removable from any extent of surface, is found to vary most materially, according to the structure of the street or roadway. Thus, roads formed of broken granite or other similar materials are rapidly destroyed by the action of wet, which loosens the superficial coating of the road, and passes into the body of the materials; the finer particles also become washed upon the surface, and act as sand in grinding it down, by the action of the wheels upon it. Paving formed with stones of irregular shapes and sizes is also productive of a large quantity of débris, although less than the unpaved surfaces just referred to. Upon this inferior class of paving, water acts destructively by washing up the soil and dirt between the stones, by which they become loosened, while a great proportion of these interposed materials have to be removed as they appear upon the surface in the form of mud. Pitch paving formed with squared blocks of granite, whin, or other stone of equal hardness and durability set in lime grouting upon a substantial foundation of concrete 9 to 18 inches in thickness, according to the nature of the sub-stratum, forms the most permanent construction for the carriage-ways of streets and thoroughfares, and afford a correspondingly small proportion of materials to be removed from the surface, in order to preserve its cleanliness. Wood paving yields the minimum of débris, and its economy, as a subject for the labours of the scavenger, at any rate, is thus very great, as compared even with the most perfect form of stone-paving.

By making the sewers thus directly available for one of their proper purposes, that of receiving the waste mat-

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ters from the streets and thoroughfares, the operation of street cleansing is reduced to mere sweeping of these matters to the side channels, which should be constructed so as to afford a ready passage for them to the sewers beneath. The economy thus obtained by dispensing with the raising and carting to distances sometimes extended may be inferred from the fact, that the average expense of sweeping and carting away the refuse of 1,000 square yards (in Manchester) in 1843 was 4s. 6d. This was performed by the ordinary hand labourers or sweepers. In London, at the same date, the mere sweeping up of the refuse from the surface of Regent Street, and depositing it in the street in loads for another process of removal, was charged at the rate of 1s. 2d. per 1,000 square yards, as executed by Whitworth's patent machine. The mere sweeping may be liberally estimated to cost 9d. for the same extent of surface, and thus $\frac{3}{4}$ths of the entire expense of street cleansing might be avoided by adopting the sewers for the purpose suggested.

Although the abandonment of all apparatus for carting and removing street refuse is here advocated, it may be useful to describe briefly the "Patent Street-Cleansing Machine," invented by Mr. Joseph Whitworth, which has been applied to a considerable extent in Manchester and elsewhere, and been considered a very promising contrivance. This will be best done by quoting the inventor's own description of his machine, as rendered in evidence before the "Commissioners of Inquiry into the State of Large Towns and Populous Districts," in 1843. "The principle of the invention consists in employing the rotary motion of wheels moved by horse or other power, to raise the loose soil from the surface of the ground, and deposit it in a vehicle attached. The apparatus for this purpose consists of a series of brooms suspended from a light frame of wrought iron, hung behind a common cart, the body of which is placed near the ground for greater facility in loading. As the cart-wheels revolve, the brooms successively sweep the

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surface of the ground, and carry the soil up an incline or carrier-plate, at the top of which it falls into the body of the cart. The apparatus is extremely simple in construction, and has no tendency to get out of order, nor is it liable to material injury from accident. An indicator, attached to the sweeping apparatus, shows the extent of surface swept during the day, and acts as a useful check on the driver. It also affords the opportunity of working the machine over a given quantity of surface. The average rate of effectual scavengering by hand in Manchester, taken for a whole year, is from 1,000 to 1,500 square yards of surface daily for each scavenger. The manner of sweeping is different in London, and therefore an apparently larger amount of work is done, but not so effectually. When the machine is in operation, the horse going only 2¼ miles per hour, it sweeps during that time 4,000 square yards; thus performing in a quarter of an hour nearly the day's work of one man. The average amount of surface which can be swept by a machine during the day depends upon the distance of the places of deposit. In Manchester we have seven places of deposit, and the average number of yards swept daily by a machine drawn by one horse is from 16,000 to 24,000."

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SECTION III.

Main Sewers: Proportions and Dimensions, Inclinations, Forms, and Construction.—Upper and Lower Connections.—Means of Access and Cleansing.—Adaptation for Street-cleansing, &c.—Cost.

In drainage, as in many other subjects, controversy has frequently been found to be excited upon those very details of the art which appear to be the most simple and the most readily deducible from observation, while the proper ground for discussion, in which it is really urgently needed, in order to determine general principles and mark out leading rules, has been left nearly or quite unoccupied. Thus the forms, sizes, and thicknesses of sewers have received the most elaborate investigation, and provoked the expression of the most widely differing opinions; while the principles of arrangement according to which the entire system should be laid out, and the great questions of the most healthful and economical disposal of the refuse of towns have, till lately, remained unsought and unasked. Misled by an instinctive adoption of the works of our forefathers, we have been content to build our sewers in old channels, and to put patch upon patch—add length to length of sluggish sewer or practical cesspool, in order to maintain ancient outfalls, while the subsidiary details of form and capacity have become the vexed questions and grounds of issue among the most practised advisers.

Not that the attention given to the details, and the neglect inflicted upon the general principles are here contrasted for the purpose of denying the importance of the former, but that, had the principles been first determined, the details would be found readily deducible from them in

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a manner and with a certitude admitting little dispute or discussion.

We have already, in the first section of this Division, shown the general principles upon which the drainage of towns should be arranged with reference to the inclinations of surface, and the means of discharging and disposing of the sewage. From these principles it immediately follows that the proper functions of sewers are twofold, and twofold only, viz., the conveyance and collection of house-drainage and of street-drainage. In the former are to be included the drainings of roofs of buildings and of yards, or other spaces attached to them. In these two purposes is thus comprised the superficial drainage of each entire town. Any attempt to add to this the drainage of the sub-formation is a mistaken and a supererogatory aim. This position will be denied by those who advocate the under-drainage of London as one of the purposes of its sewerage. Let us endeavour to understand the practical value of this purpose, and thence deduce the infinitely small amount that would be mis-spent in any attempt to realise it. If the proper functions of sewers be effectually discharged, viz., the conveyance away from a town of all the rain-water that falls upon its surface, and of all the solid and liquid refuse produced in streets and buildings, what will be the amount of submoisture which it can be necessary or desirable to abstract in the form of land-drainage? The entire surface being maintained constantly dry, the only sources from which under-water can arise will be springs or water-bearing strata beneath, and wherever these may show themselves, they can be turned to good account, and the water they yield converted to useful purposes, without making expensive provision for their drainage beneath. Whatever relation the site of a town may have to the surrounding country, that is to say, whether the town be above or below the lands around, or be on a similar level, none of the drainage-water from these lands should be permitted to enter the town or to mingle with the soil beneath it. This

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is to be effected by constructing around the town a system of encircling catch-water drains, by which so much of the surrounding drainage as would otherwise find its way into the subsoil of the town will be intercepted and collected, either to be returned by suitable channels to the rivers, streams, and watercourses, to be made available in irrigating adjacent districts, or diverted directly from the catch-water drains into the main sewers of the town itself, and disposed of with their contents. With this auxiliary arrangement for preventing the access of surrounding drainage to the sub-formation of the town, all necessary provision for maintaining it in a dry and healthy condition will be completed, and no necessity can possibly arise for constructing a duplicate system of sewers in order to drain the subsoil of the town. With all due deference to official experience, we venture to predict that, if ever tried, the "system of permeable land-drains and sewers," as a separate addition to the "system of permeable drains for house and soil drainage," will be found as utterly useless in practice as it will be expensive in construction.

The proportions, dimensions, inclinations, forms, and construction of main and all other sewers, are all more or less effected and determinable by the general system of drainage adopted. We will first cull from the mass of recorded experience at our command (up to the year 1843) some detailed particulars of modes of construction (and their cost), many of which have been found inefficient in fulfilling the self discharge of the sewage matters of London and other towns in England.

The experience in the City of London led the surveyor to the Commissioners of Sewers to consider that the form of a semicircular top and bottom, with straight (or vertical) sides, "answered all the conditions of a sewer." Nevertheless, many have been constructed of an oval form. The smallest size in a long street is 4 feet 6 inches by 2 feet 6 inches. The other sizes are 5 feet by 3 feet; but several are considerably larger, where much water is

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expected to accrue from the outer districts. The outlet for the main sewer at South Place (Finsbury) is 6 feet 6 inches by 4 feet 6 inches. The Fleet sewer, which drains from the south-west of Highgate, is 18 feet 6 inches by 12 feet at the mouth, and 12 feet 3 inches by 11 feet 7½ inches at the city boundary; and owing to the immense quantity of water flowing into it, "this sewer has often been surcharged." The Eldon Street (Finsbury) sewer is 5 feet by 3 feet 2 inches; the London Wall sewer is 6 feet by 4 feet, and the main trunk increases from 8 feet 3 inches by 6 feet 9 inches to 10 feet by 8 feet at its mouth. For courts and alleys the sizes are 3 feet by 2 feet 2 inches, and sometimes, according to the number of houses, 4 feet by 2 feet 4 inches. The sewers 4 feet 6 inches by 2 feet 6 inches are built in brickwork 14 inches in thickness throughout. Adapting the size of the smaller drains so as to admit a man to pass through them, they should be at least 2 feet in width, and, to allow crawling through, 2 feet 4 inches or 6 inches in height; to allow his crouching through, 3 feet 6 inches; or to stoop through, 4 feet 6 inches. The thickness of brickwork of these sewers should not be less than 9 inches, nor the depth from the ground less than 12 feet at the shallowest part, in order to provide for the drainage of a basement story about 7 feet 6 inches in height. Assuming 2 feet 6 inches as the minimum height for a common sewer, and allowing 20 inches of deposit to exist in a public sewer before it can rise into the common sewers, the surveyor deduced a minimum height for public sewers of 4 feet 2 inches.

In the Westminster Division of Sewers the level of the outfalls into the river varies from 10 to 15 feet below the level of high-water mark, and some of them have flaps. Some of the main sewers have a fall of only half an inch to 100 feet. The form of the sewers is that of a semicircular arch at the top, and a segmental invert with upright sides. The two sizes used are—first class, 5 feet 6 inches high and 3 feet wide; and second class, 5 feet high and 2 feet

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6 inches wide. The three centre courses of every invert are built in cement, and the remainder of the work in Dorking lime-mortar. The walls are 1½ brick in thickness, and the arch and invert 2 half-bricks, or 9 inches. The cost for a sewer 3 feet wide was, for the brickwork, 14s. 3d. per foot; and for a sewer 2 feet 6 inches wide, 12s. 6d.

The sewers throughout the Holborn and Finsbury Divisions discharge into the main sewers of the City of London, and have no outfalls of their own into the Thames. The Fleet sewer conveys the drainage of about 4,444 square acres of surface in those divisions, and is calculated to receive annually from this surface about 100,000 cube yards of matter held in mechanical suspension, and carried to the Thames by the force of such waters as flow through the sewer. These waters, by the experiments of Mr. Roe, having been found to amount to about 100 times the bulk of the matters held in suspension by them, it follows, that the Fleet sewer discharges from this surface about 10,000,000 of cube yards of sewage-water and suspended matters into the river Thames annually. The total work of this sewer comprises also the quantity it receives from the surface of the city, after passing through the district here referred to. A sewer carried up to Holloway, in this division, a length of nearly 3 miles, passes under Canonbury (Islington) at a depth of 68 feet from the surface, and the drainage of the houses in that part is provided for by a subsidiary sewer.

Sewers constructed on the Kingston Estate, through a very soft clay, are built of an oval form, the largest size being 3 feet 6 inches high and 2 feet 6 inches wide, the radius of the side curves about 3 feet; half a brick thick in cement. The extent of cutting was from 16 to 18 feet, and the cost 15s. per lineal foot. The fall at the rate of 80 feet in a quarter of a mile.

The practice in some of the provincial towns was reported as follows:—

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Lancaster, Fig. 74.—Flag or slate bottom. Rubblestone sides, laid in common mortar. Rough stone covers. Mains 2 feet 6 inches × 1 foot 4 inches, 6s. per lineal yard. Branch street drains, 1 foot 4 inches square, 4s. 6d. ditto. Yard drains, 6 or 7 inches square, 2s. ditto. All found to be very inefficient.

Nottingham, Fig. 75.—Brick. Cylindrical sewers. Upper half built in mortar. Lower half laid dry. Half-brick thick. Diameter from 2 feet to 2 feet 6 inches. Average cost 7s. per lineal yard.

Birmingham and Walsall.—2 feet circular culverts laid 5 feet deep. 7s. per lineal yard.

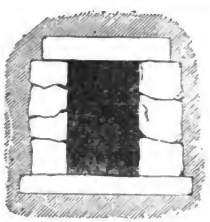

Fig 74.—Lancaster.

Fig. 75.—Nottingham.

Chester.—Circular brick drains from 30 to 36 inches diameter. Average cost 12s. per lineal yard.

Bristol, Fig. 76.—Four sizes of elliptical brick sewers :—

	ft.	in.		ft.	in.	
1st.	4	0	×	3	0	Internally.
2nd.	3	3	×	2	6	,,
3rd.	2	8	×	2	0	,,
4th.	2	0	×	1	6	,,

All 9 inches thick.

Cylindrical drains, 1 foot 2 inches in diameter internally, 7 inches thick.

Rate of fall from 1 in 60 to 1 in 360.

Frome.—Stone and lime cheap and abundant. Drains or "gouts," 18 inches square, covered with stone, to take any weight, exclusive of digging, 2s. per lineal yard.

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Culverts 2 feet square, dry walls, with rubbed stone arch, turned in good coal-ash mortar, exclusive of digging, 4s. 9d. per lineal yard.

Swansea.—Oval drains, 3 feet 2 inches × 2 feet, including excavation, 10s. 6d. per lineal yard.

Cylindrical drains, 2 feet diameter, including excavation, 8s. per lineal yard.

Brecon.—Cylindrical drains, 2 feet diameter, cost 8s. per lineal yard.

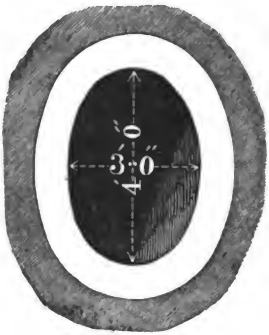

Fig. 76.—Bristol.

Square drains, side walls of dry masonry, with flat covering stone, from 3 to 4 inches thick.

Cost:—12 inches, 2s. 6d. per lineal yard.
15 inches, 3s. 3d. ,,
18 inches, 4s. 0d. ,,

The egg-shaped or oviform section used in the Holborn and Finsbury divisions is shown in Fig. 77, and the section commonly used in the Westminster division up to the year 1843 is shown in Fig. 78. The difference in expense between sewers of these sections has been estimated at £1,660 per mile, upon the following data. Brickwork at 20s. per cube yard. Excavation, 1s. per cube yard. Filling in, 3d. per cube yard. Carting, 2s. per cube yard. Remaking surface, 1s. 6d. per superficial yard. Average depth of excavation, 20 feet. The quantities per mile of

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each sewer are shown in the following table, the size of the egg-shaped sewer being 5 feet 3 inches by 3 feet

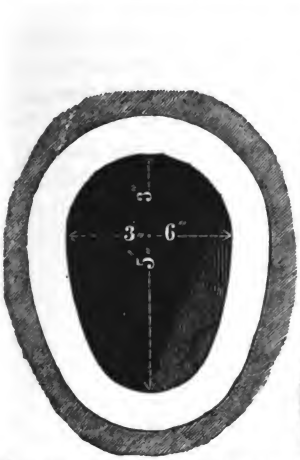

Fig. 77.—Holborn and Finsbury.

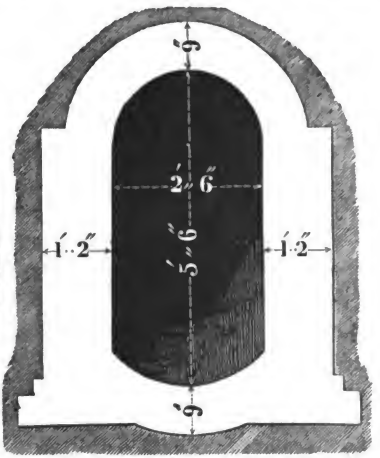

Fig. 78.—Westminster.

6 inches, and that of the upright-sided sewer 5 feet 6 inches by 3 feet.

	Finsbury, or egg-shaped sewer.	Westminster, or upright-sided sewer.
Bricks consumed . . .	924,140	1,378,080
Cube yards of brickwork .	2,272	3,388
Do. do. excavation .	19,555	25,420

Excess in Westminster Sewer, per mile.

1,116 cube yards of brickwork at 20s. .	£1,116	0	0
5,865 ,, excavation at 1s. .	293	5	0
5,865 ,, filling in at 3d. . .	73	6	3
1,116 ,, carting at 2s. . .	111	12	0
880 super yards repairing at 1s. 6d. .	66	0	0
Total	£1,660	3	3

One of the Westminster sewers, built in the Harrow Road, according to the section, Fig. 78, failed, owing, as alleged, to some difficulties in the nature of the soil, and to imperfect workmanship. This was replaced by another

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form of sewer, which is shown in Fig. 79, in which the shaded parts represent brickwork in cement, the invert and springers being bedded in concrete as high as the 14-inch work, as there shown.

The capacity of sewers is determined by a consideration jointly of the quantity of sewage to be conveyed through them, and of the rate of inclination or fall in their vertical position. The capacity varies directly as the quantity and inversely as the fall, since the greater the fall the

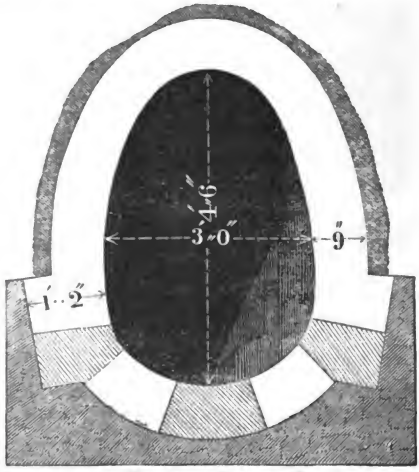

Fig. 79.—Harrow Road.

more rapid is the discharge. It has been usual to prescribe another limitation as to the minimum capacity of sewers, viz. that they shall at least, under all circumstances, be large enough for a man to pass along them. The necessity for this allowance has arisen from the fact that sewers are found to require cleansing by hand—that it is utterly impossible to remove the accumulations which are liable to occur within them by any other means, and thus some £10,000 has been annually expended in London alone in an employment of a most disgusting and dangerous

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nature. There need be no hesitation in saying that, under a thoroughly efficient and practicable system, no such process could ever be needed, and, moreover, that if deemed desirable for any possible purpose, it would apply only to the principal sewers, the size of which would admit of it, as determined upon the joint data of quantity and fall alone. This condition may therefore be dismissed from the problem, and it may be studied upon the two data named.

Since the quantity of sewage due to any given extent of surface will depend mainly upon the amount of population to be served, it follows that in an equalised system aiming at an uniform size for the sewers of the several classes, the points of collection or receiving-wells should be arranged at distances varying inversely as the density of the population. Now the maximum density of the population of London is estimated at 243,000 to a square mile. Let us suppose the drainage of one quarter of a square mile of surface, populated to this extreme degree of closeness, to be conveyed in one main sewer, and endeavour to form a rough notion of the total quantity of sewage which this sewer should be fitted to convey and discharge. The entire bulk of sewage must consist chiefly of the house-sewage and rain-water from the surface—at least the other constituents are of too insignificant an amount to require notice in a merely approximate estimate. And similarly the entire house-sewage may be assumed as equal to the bulk of water delivered to the total population. It has been calculated that 20 gallons are, or ought to be, allowed to each individual of the population per diem. The annual quantity will therefore be $20 \times 365 = 73{,}000$ gallons, or say 1,200 cubic feet. The population of the square quarter of a mile being $\frac{243{,}000}{4}$, or about 60,000, this number multiplied by 1,200 cubic feet for each person will produce 72,000,000 as the annual quantity of sewage in cubic feet arising from this population. To this is to be added the bulk of the rain-water, which we

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will allow to amount to 24 inches, or 2 feet, in depth annually over the surface, and that this quantity will be discharged into the sewer without further diminution by evaporation. The total quantity to be drained annually from the surface of a quarter of a square mile will thus amount to $2{,}640^2 \times 2 = 13{,}539{,}200$ cubic feet. Adding this, which we will call $13\frac{1}{2}$ millions, to the 72 millions of house-sewage, we obtain a total of $85\frac{1}{2}$ millions of cubic feet of sewage to be discharged per annum from the surface of a square mile of the most densely-populated part of the metropolis. If this annual quantity were in a state of constant transition along the sewer, and with equal velocity throughout, and the effect of friction was for the moment disregarded, the proportion to be passed per minute would be of course easily calculated, being 85,500,000 divided by 525,600 (the number of minutes in a year), or 162·66 cubic feet. Now a recorded fact will be a more useful datum for our calculation here than any elaborate investigation of velocities, friction, &c., and we will therefore refer to the experiments of Mr. Roe, instituted for testing the value of the flushing system as applied to sewers, and which showed that the sewage passed through the River Fleet sewer with an average velocity of 83·47 feet per minute; the run of water being spread over a surface 10 feet in width, and the stream being only 10 inches in depth: the passage every minute, therefore, was equal to 692·8 cube feet of sewage, and the friction in this case being greater than if the same sectional area of water had been accumulated in a cylindrical drain of smaller diameter. The solid matters held in suspension by this water amounted to the proportion of 1 in 96 of the bulk of water, and consisted, as all sewage usually does, of decomposed animal and vegetable matter, and detritus from streets and roads. At this rate of transit, it appears that a sectional area equal to 2 square feet would suffice to pass the entire sewage of a thickly-populated area of a square quarter of a mile, supposing the passage to be constant and uniform,

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and the fall of the sewer and friction of the sewage equal to that of the River Fleet sewer, on which the experiments were made.

In modifying this result to provide for the difference between the assumed and the real nature of the transit, we will first admit that the bulk of the sewage, consisting of that flowing from the houses, is delivered into the drains during perhaps half the real time, that is, during twelve instead of twenty-four hours. The sewers will, therefore, be required to discharge double the quantity estimated during each alternate period of twelve hours, and during the intervening periods of like extent to remain empty. We will therefore double the capacity, and allow 4 square feet of transverse sectional area of main sewer for the drainage of the given surface.

But we have another allowance to make: we have the "storm-waters" to provide for, about which we have heard so much, because occasionally, during the rainy month of July, a smart shower is observed to cover a flat street, or form ponds on the low side of an ill-formed roadway. Let us estimate the allowance required for this phenomenon, and infer the advisability of providing for it in the sewers. We have seen that 24 inches in depth of rain falling upon our selected spot will equal a total bulk of 13½ millions of cubic feet. We will suppose an extraordinary case, viz. that some July day the whole quantity due to a month (2 inches) falls in twenty minutes. Then, in order to prevent any flooding of the thoroughfares, this quantity, equal to $\frac{13,500,000}{12} = 1,125,000$ cubic feet, will have to be disposed of in twenty minutes. Assume that the velocity produced by the pressure on the water will equal 1,000 feet per minute. What would be the capacity of the sewer equal to discharge this rain-water as rapidly as it falls from the clouds? The quantity accruing per minute being $\frac{1,125,000}{20} = 56,250$ cubic feet, and the velocity equal to

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1,000 cubic feet, the capacity of the sewer must be equal to 56¼ square feet of transverse sectional area. Now we have found that an area of 4 feet will suffice ordinarily for the house-sewage. Is it desirable to increase the capacity of our sewers fourteenfold in order to provide for an occasional shower? There can be no necessity to answer the query? Economy of the most liberal disposition would not sanction any such arrangement. If the exact area of 4 feet be doubled, in order to make ample provision for all ordinary contingencies, it will satisfy every reasonable requirement; and then by suitable inlets to the sewer, the deluge of rain-waters will be prevented from overcharging it, and the effects of the shower will disappear in some hour and a half, and before any very serious mischief can be produced by the water soaking into the subsoil through well-paved streets and yards.

In proportion as the population is more extended, the ratio of house-sewage to surface-sewage will of course diminish, and vice versâ; but we believe that economy and facility of drainage will be best promoted by limiting the sum of population and area to each receiving well, so that a transverse sectional area of 8 or 9 feet shall suffice for the main sewers.

In the suburban districts of a town, where comparatively large surfaces exist in gardens, and where, therefore, the effect of allowing the "storm-waters" to gather might be productive of mischief by saturating the soil, the diminished amount of house-sewage will tend to make the operation of the mains more effective in relieving the surface, besides which, natural declivities will usually aid the fall of the sewers, and provision might frequently be made at little cost for receiving the surface-water in auxiliary wells or receptacles in which it could be made available for subsequent service in irrigation, without allowing it to burden the main sewers of the district.

Having based our calculation as to the capacity of main sewers upon an area of the maximum density of popula-

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tion, we will, with the same view of providing for the utmost necessities, consider the question of declivity or fall as to be applied to that description of natural surface which presents the greatest difficulties to the operation of any system of sewage—a perfect or dead level. Wells or receptacles for the sewage being placed half a mile distant from one another, so that the area drained into each of them equals a square quarter of a mile (or each side 2,640 feet long), half of this, or 1,320 feet, may be taken as the length of each of the main drains. The longest of the main sewers thus measuring 1,320 feet, the fall is to be computed with reference to this length. We have seen that metropolitan sewer-practice has recognised a fall of half an inch in 10 feet or 1 in 240, as sufficient for all the purposes of good drainage. At this rate the fall due to 1,320 feet will be 5 feet. But preferring to allow double this fall as proportionally improving the system, by aiding the discharge, we should require a fall of 11 feet in our main sewers of the maximum length. And preserving 5 feet above the head of the main, it would lie at a depth of 16 feet at the well. This 5 feet will usually be found sufficient to allow all necessary fall in house-drains and in branch sewers, to serve the superficial draining of the intervening district.

The utmost economy of the system would be attained by multiplying the main sewers as much as possible, as by this means the length of the branches may be reduced to a considerable extent, and the necessary depth of the mains also reduced correspondingly. On the other hand, by sparing the main sewers, they are required to be laid deeper, and the branches also; or, if the depth be saved, it is at the expense of efficiency, and the whole system is instantly filled with insuperable difficulties in vain attempts to reconcile the relative levels of an infinite number of collateral sewers, and to adjust the details of the arrangement to the minor variations of surface above.

In the depths we have assumed, as deduced from the

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desirable rate of inclination for the main sewers, allowance is not yet made for draining the basement storeys of the buildings. It must be confessed that this purpose involves the greatest difficulty in the details of the system. On the one hand, it is evident that the construction of sewers as large as rivers, and at depths varying from 20 to 70 feet below the surface, demands a most extravagant expenditure at the outset, and, after all, puts the works in positions which are practically inaccessible. Yet, on the other hand, we shall be reminded that the deep basements and kitchens must be provided for, and that our branch sewers must be sunk low enough to serve even the lowest of these. In order to provide for these, the main sewers will need to be laid some 8 or 10 feet lower than the depths we have given, viz. 13 or 15 feet at the head, and 24 or 26 feet deep at the well. Rather than permit the evils caused by sinking sewers at these depths, it will probably be preferable to reduce the distance between the wells, or even admit (although highly objectionable) some diminution in the rate of fall. We are satisfied, however, that the fullest investigation into this subject will establish the principle that no sewage matters of any kind whatever should be allowed to be discharged into a sewer from any rooms or apartments below the surface of the ground. The difficulties which would attend any attempt to carry this principle into effect in London and similarly ill-constructed cities, may be too formidable to be now encountered, but they must be overcome before the sewerage of such towns can be reformed upon the most efficient plan which our present knowledge and experience suggest.

The dimensions of the branch sewers are to be determined upon the same two elements of population and surface to be served that we have referred to in estimating the required capacity for the mains; and, according to the varying extent and proportion of these elements, a scale of sizes may be determined for the several lengths, distances apart, &c., of the branch sewers.

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By the system of district collections here recommended, one great difficulty felt in planning sewers for concentrated discharge is at once obviated. In forming sewers which are intended at the time to serve a certain district, but which may hereafter be treated as trunks, and called upon to discharge constant accessions of sewage from an extending neighbourhood, no calculation can possibly be made as to the sufficiency or otherwise of the section it is proproposed to adopt. Thus, as truly remarked by the surveyor to the City Sewers Commission, "the sewer from Moorfields to Holloway appears to measure upon the map about three lineal miles. In process of time, and as buildings increase, it may throw out branches in all directions, and the three miles may become thirty. Not only all the atmospheric waters which may, upon an average, fall within the valley south-eastward of Highgate (or at least a large portion of them), but all the artificial supplies which the wants of its yet future inhabitants, as well as of those intermediate between Islington and Moorfields, may require, will have to be carried off by the City sewers." The necessary consequence of which doubtful condition is, either that the sewers are at first constructed in a most extravagant manner as to dimensions and depth, or that they are afterwards found to be utterly inadequate to their increased duty, and have to be reconstructed at greater depth and of enlarged capacity. Whereas, if district collections are adopted, each main sewer is at once properly devised as to size, form, and construction, and continues to perform its services efficiently; and as new districts are formed, each of them is provided with another system of sewers adapted to its defined limits, and made sufficient for all the work it will be ever expected to perform.

In the form of sewers two conditions have to be fulfilled, viz. strength, as obtained with economy of cost, and efficiency of action. A hollow channel embedded in the subsoil is evidently liable to be pressed upon and against by

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the weight and bulk of the surrounding solid materials, and it therefore becomes necessary that the form of this channel be such as will enable it to resist effectually this pressure from without. We all know that a curved form of construction, in which the convex surface is opposed against the pressure, is stronger in this way than a plane surface, because the pressure applied to any point of the convex surface is immediately distributed to all the surrounding points on that surface, and their combined resistance is thus brought into action against the external force. And since the complete co-operation of all parts of the surface in resisting uniform pressure from the exterior is obtained only when all those parts have a common centre, the circle is the most perfect figure for this purpose.

But the pressure upon all parts of a sewer is not uniform. The top of it will be subject to the entire weight of the mass above it, minus only the friction and structural tenacity by which that mass is prevented from moving freely downward from the surrounding portions. The sides of the sewer are pressed against by the soil with forces inversely proportional to the tenacity of the material; that is to say, the less the tenacity or power of self-support, the greater will be the pressure against the sewer. The bottom of the sewer may be regarded as free from external pressure, except such as is due to the resistance with which the soil below meets the downward pressure exerted by the sewer itself, and transmitted by it from the load above.

The greatest pressure being thus vertically from above, a form of uniform strength would require to act with greater resistance in this direction. Hence an elliptical form, the longest diameter being placed vertically, would appear to answer the conditions better than a circle, and is, doubtless, the least imperfect form that can be adopted. Practically, it has been deemed desirable to combine, as far as possible, a considerable capacity with the means of making a reduced flow active in its passage through the sewer; and these requirements appear to be fulfilled by a

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form of section that differs from an ellipse in having the upper curve of larger radius than the lower one, resembling the outline of an egg standing on its smaller end, and to which the name of egg-shaped, or oviform, has therefore been applied.

The value of the curved bottom of reduced radius depends upon the well-known law, that the passage of fluids through channels is retarded by the friction between the water and the surface of the channel with which it is in contact. And it is an evident result of this law, that the greater the surface of contact the greater the friction. Hence, any given bulk of water will flow the most rapidly in that form of channel in which this surface of contact is reduced to the minimum. The form necessary to fulfil this condition is presented at once by the well-known geometrical principle, that the circle includes a greater area within its perimeter than any other figure of equal perimeter. And as the necessity for aiding the flow by diminishing the friction occurs chiefly when only a small stream exists within the sewer, it follows that the radius of curvature should be proportionally reduced within practical limits.

The exact proportion which the radii of the upper and lower curves of the oviform section of sewer should bear to each other (adopting circular curves as preferable in practice to elliptical or any indefinite curves) would depend on the precise average minimum of water to be provided for, calculated jointly with the density and tenacity of the soil, and the depth at which the sewer is laid. As it is manifestly impossible to determine all these elements with exactness in evolving any general rule for the proportions of the section, they may be disregarded, since the main form is established by the conditions already stated; and a practical rule may be formed which will be found to answer all real purposes.

In the forming of sewers, as in all works of a similar class, which are often necessarily intrusted, to a great

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extent, to the charge of workmen, who cannot be expected to pay much attention to the refinements of geometrical principles, simplicity is evidently an object of the first importance. The proportions of the several curves required in marking out the section and forming the moulds and gauges to be used in constructing and testing the work should be such as can be readily understood and exactly remembered; and in proportion as these rules are observed in designing the form, will be the probability of that form

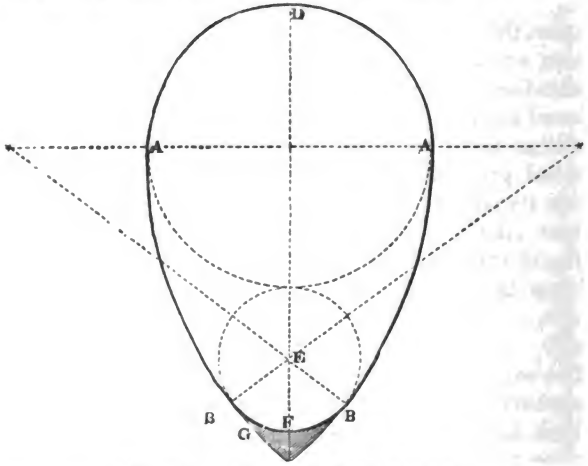

Fig. 80.—Standard Section of Sewers.

being preserved, and exactness attained in the construction of the sewer.

In seeking this object, a diagram of proportions, shown in Fig. 80, has been worked out, which may be recommended on the score of simplicity and sufficiency, as may be made evident by the figure and the following description. In this section, let the diameter A A, of the upper semicircle A D A equal 1; that of the lower arc B B will equal ·5. The entire height of the section D F will equal 1·5, and the radius C A A, of the side arcs A B (truly tan-

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gential to the upper and lower arcs) will also equal 1·5. The centres C C being upon the produced diameter of the upper arc, that arc will equal a semicircle, and the lower arc B B will equal 120°, the points for the meeting of the curves being at B B, found by drawing the radial lines, C B, through the centre E of the lower arc. Suppose the greatest diameter A A be determined at 3 feet, the several dimensions will be thus :—

	Ft.	In.
Diameter of upper arc	3	0
Do. of lower arc	1	6
Height of section	4	6
Radius of side arcs	4	6

And the area may be taken (as a very close approximation to the truth) as equal to that of a semicircle of 3 feet diameter, added to the area of a circular segment whose radius is 4 feet 6 inches, and versed sine 1 foot 6 inches; the area thus given being in excess only the small space shown in shaded lines at G.

The construction of sewers is varied according to their size, and should be also considered with reference to the economy with which different materials may be obtained according to the locality of the district, and also the nature of the soil in which the work is constructed. For the smaller sewers the "glazed stone-ware" pipes are found efficient substitutes for those built up of brickwork. They have the advantages of being much more quickly laid than the others can be built, and of presenting a very superior surface for the rapid passage of the sewage. They are also constructed in various forms of bends and junction pieces, and thus afford the means of insuring proper form in these points. From their comparative thinness, pipes of this kind afford a much larger capacity with a given quantity of excavation for laying them, than sewers formed of brickwork, which, even for the smallest diameter, cannot be less than half a brick, or 4½ inches in thickness. In laying them care must, of course, be taken with the joints, which are formed by a socket on one end of each length of pipe

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in which the plain end of the adjoining length is received. The prices at which these pipes may be procured in London are as follows :—

Straight Pipes with Socket Joints.

	Inches bore.	Price per lineal foot. s. d.
In 3 feet lengths	2 ..	0 4
,, ,, ...	3 ..	0 5
2 feet ,, ...	4 ..	0 6
,, ,, ...	6 ..	0 8
,, ,, ...	9 ..	1 1½
,, ,, ...	12 ..	1 10
,, ,, ...	15 ..	3 0
,, ,, ...	18 ..	4 0

Diameter of bore.	Bends each.	Junctions each.	Double junctions each.
Inches.	s. d.	s. d.	s. d.
2	1 0	1 0	1 4
3	1 3	1 3	1 8
4	1 9	1 6	2 0
6	2 3	2 0	2 8
9	3 6	3 6	4 6
12	5 6	5 6	7 0

Egg-shaped pipes are also prepared of the same material in 2 feet lengths with socket-joints, at the following prices :—

Size inside.				Price per lineal foot s. d.
ft.	in.	ft.	in.	
1	8 ×	1	0 ..	3 6
1	3 ×	0	9 ..	2 3
0	9 ×	0	6 ..	1 1

In Chester the following prices have been paid, including excavation of the maximum depth of 12 feet :—

Inches.	s. d.	
42 × 32	11 0	per lineal yard, ordinary earth.
42 × 32	15 2	,, rock.
36 × 28	9 6	,, ordinary earth.
33 × 25	8 6	,, ,, ,,
30 × 22	7 9	,, ,, ,,
24 × 18	6 6	,, ,, ,,
20 × 15	5 6	,, ,, ,,
15 × 12	4 9	,, ,, ,,

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The stone-ware pipes may be manufactured with ample strength for all purposes required in their application as minor sewers. Some experiments, made with specimen pipes of fire-clay at Glasgow, proved their power to resist a pressure equal to that of a perpendicular column of water 900 feet in height, being three times the pressure to which it is found necessary to prove iron pipes used for the transmission of water. Drain pipes of common clay are supplied in Glasgow at the following prices:—

	s.	d.	
3 in. diameter . . .	0	6	per lineal yard.
6 ,, . . .	0	9	,,
9 ,, . . .	1	0	,,
12 ,, . . .	1	3	,,
18 ,, . . .	2	0	,,

Pipes of fire-clay at Glasgow, cost—

	s.	d.	
4 in. diameter . . .	1	0	per lineal yard.
6 ,, . . .	1	6	,,
12 ,, . . .	2	3	,,

Supplied in large quantities, it is presumed that all of these prices for tubular sewers would admit of considerable reduction. The following estimates for works, as ordered by the Metropolitan Commission of Sewers, in the months of April and May, 1849, contain some useful figures as to the cost of works of this class:—

Quantities.	Localities.	Estimated cost. £	s.	d.
245 ft. of 12 in. pipe sewer . . .	To be put down an open sewer in Southampton Street, Nine Elms, Surrey	39	0	0
400 ft. of 9 in. and 500 ft. of 12 in. .	To be put down in St. Mark's Road, Kennington	131	5	0
485 ft. of 12 in. .	To be put down in James Street, Kennington	78	16	3
400 ft. of 9 in. and 415 ft. of 12 in. .	To be put down on the south side of Kennington Common	117	18	9
700 ft. of 4 in. .	To be put down on the north side of Kennington Common . . .	15	0	0
483 ft. of sewer, 3 ft. 6 in. by 2 ft. 3 in.	To be put down in the Wyndham Road, Camberwell	157	0	0

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Quantities.	Localities.	Estimated cost. £ s. d.
95 ft. of 18 in. pipe sewer	To be put down in Great Guildford Street, Borough	28 10 0
135 ft. of 15 in.		26 0 0
665 ft. of 9 in.	In an open ditch	78 10 0
800 ft. of half-brick sewer, 3 ft. 6 in. by 2 ft. 3 in. and 158 ft. of 12 in. pipe sewer		300 0 0
240 ft. of 9 in.		15 0 0

From these estimates the average costs of supplying and laying the pipe sewers of several sizes appear to be as follow:—

	s.	d.	
4 in.	0	5·14	per foot.
9 in.	1	3	,,
12 in.	3	3	,,
15 in.	3	10	,,
18 in.	6	0	,,

And of tne egg-shaped sewer, half a brick thick, and measuring 3 feet 6 inches by 2 feet 3 inches, 6s. 10½d. per foot.

In commonly good soils brick sewers may be constructed of a single half brick, or 4½ inches in thickness, of curved form, of considerable size. In the Finsbury division, half-brick egg-shaped sewers have been constructed, 4 feet 6 inches by 2 feet 9 inches, and are found sufficient. Sewers of these dimensions would be ample for the mains of properly limited and defined districts. If the soil be of a loose and uncertain character, it will be necessary to build them 9 inches in thickness, or two half-brick rings. In the small curve of the invert all brick-built sewers should be very carefully constructed, the unavoidable interstices between the bricks (if of the common square form) being filled in with pieces of slate or tile, and the whole floated in with cement to make it as one solid mass. If this be not honestly done and carefully superintended, the action of the declivity will be nullified by irregularities in the interior surface of the waterway, and a liability created to the formation of bars by the settlement of the solid portions of the sewage. Egg-shaped sewers 3 feet 6 inches by

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2 feet 6 inches, in an average excavation of 15 feet, have been executed at a cost of about 14s. per lineal foot in the neighbourhood of London. These sewers were built half a brick in thickness and in cement throughout, and the cost included excavation and refilling the soil.

Egg-shaped sewers formed according to the rule given, built half a brick in thickness and with inverts in cement, in an average excavation of 10 feet, may be estimated to cost per lineal foot as follow:—

	ft.	in.		ft.	in.	s.	d.	
Class 1 .	4	0	×	2	8	10	0	per lineal foot.
„ 2 .	3	6	×	2	4	8	6	„
„ 3 .	3	0	×	2	0	7	0	„
„ 4 .	2	6	×	1	8	5	6	„
„ 5 .	2	0	×	1	4	4	6	„

In forming the connections of sewers with each other, viz. those of the house drains with the branch drains or sewers, and of these with the mains, through the several classes of sizes which it may be necessary to adopt, two rules should be in all cases imperatively insisted upon: first, that all junctions shall be formed with curves, and of as large radii as possible in the direction of the current; and secondly, that wherever a minor drain discharges into a larger one, the bed of the former shall be kept as much as possible above that of the latter as the relative sizes of the two sewers will admit.

The importance of the first of these rules has been long recognised and admits of proof, both theoretical and practical. It is found that in a sewer of 2 feet 6 inches in width, a stream of water, flowing with a velocity equal to 250 feet per minute, meets a resistance in suffering a change of direction, the amount of which depends upon the directness with which that change is made; the resistance occasioned being three times as great by a right angle as by a curve of 20 feet radius, and double that produced by a curve of 5 feet radius. The resistance thus diminishes as the radius of curvature of the junction is increased. The effect of junctions in which considerable resistance is op-

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posed to the passage of the sewage is, that the solid particles become deposited, and, being left by the flowing water, they accumulate until a bar is formed, which still further impedes the progress of the sewage, and eventually arrests it altogether.

The practical value of keeping the mouths of minor sewers above the level of the bed of the mains into which they discharge, arises from the prevention by this means of a return of the sewage up the minor drains, supposing a deficient declivity or any untoward circumstance should produce a retrograde movement within the main. The connection should also be formed in the most perfect manner, so that the mingling of the currents shall not have the effect of impeding either of them. The mouth of the minor drain should be spread into a bell form, and the whole surface of the junction made solid and even with good cement.

The upper connections of the minor sewers, viz. with the house drains, are small works, requiring the greatest care and circumspection. They are frequently disregarded and carelessly executed, because they appear individually trivial matters; and, moreover, are troublesome and tedious, and correspondingly expensive. But it is clear that the efficiency of the entire arrangement of any system of town drainage is primarily dependent upon the completeness with which the individual drains of houses convey the separate contributions of sewage into the minor or branch drains. If these tributaries fail, the trunk of course remains idle, and all care bestowed on the larger works is thrown away. Supposing the house-drains to be formed with clay or stone-ware pipes, and the receiving branch sewer to be of the same material, lengths of the latter should be introduced at intervals, having sockets into which the ends of the house-drains may be fitted. If the branch sewer be of brickwork, the junction of the house-drains should be carefully made good with a ring of cement, and the work nicely finished on the interior surface. It will of course be

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necessary to lay these house drains and branch sewers at the same time (if the latter are of brickwork and not large enough to admit a workman), in order to complete this work in the best manner. And as this is not always convenient, the stone-ware pipes offer the great advantage of jointing without any hand work inside the branch, by simply laying the branch sewers with sufficient socket outlet lengths at intervals, which may be communicated with by house-drains at any future time, the sockets being temporarily plugged up with wood.

The lower ends of the main sewers will communicate with the receiving wells, and should be well lipped downwards to promote the ready discharge of the sewage the moment it arrives at the mouth. These being principal works, and few in number, are more likely to be well attended to and carefully executed than the multiplied minor connections. The wells, adapted in capacity to the quantity of sewage they are intended to contain, will require substantial and sound work. Being in towns necessarily sunk to some depth in the ground, the cylinder will be the best form in which to construct them. Behind and around the brickwork a backing of concrete should be filled in, the excavation being made sufficiently large for this purpose, and the whole interior surface should be lined with cement or asphalte. If this be done it will not be necessary to build the work in cement, although this would, perhaps, be a wise additional precaution. Proper economy in this matter will be best arrived at by experiments, upon which an adequate sum of money would be well expended before extensive operations are commenced.

Means of access to the main sewers are best afforded by side entrances, such as those which have been introduced in the Holborn and Finsbury division for the purposes of inspection and flushing. Although, if the entire system were properly constructed, no necessity could occur for artificial cleansing, it will be desirable to provide means of getting at the interior of the main sewers at intervals, and

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the side entrances referred to are well adapted for this purpose. The side entrance consists of a vertical square or rectangular aperture, formed in brickwork, and covered by a hinged iron cover, fitted in the foot-pavement of the street. This aperture is carried down to a level of about 2 feet above the bed of the main sewer, and terminates in a short passage or tunnel, which opens into the side of the sewer. The vertical entrance is provided with hand-irons, built into the wall, by which ascent and descent are rendered easy.

We have already insisted on the necessity of so arranging and constructing the sewers of a town that they shall not require any cleansing by hand, and have denied the condition of admitting workmen as an essential one in determining the size of sewers. A sewer cannot be considered as properly constructed if it retain the matters committed to it in a quiescent condition. It should act simply as a place of passage, and instantly transfer the sewage onward towards the receiving well. Failing in this purpose, and containing all the solid matters in a constantly-growing accumulation, the sewers of a town act as combined cesspools, and the several gulley-holes serve as the outlets for the escape into the atmosphere of some of the deadly gases constantly engendering below. The expense of cleansing by hand is, moreover, an item of considerable importance, although, of course, never incurred until the subterranean nuisance becomes intolerable. In the Holborn and Finsbury division, the cost of removing the soil from the sewers provided with man-holes has been about 7s. per cubic yard, and from those without, 11s. per cubic yard, including the expense of breaking the arch and making it good again.

The method of cleansing the sewers in which matter accumulates, by flushing water through them, was practised to a great extent in the Holborn and Finsbury division of sewers. The principle of this method consists simply in retaining the sewage water for a period of time by flushing gates fitted in the sewer, and periodically

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admitting the accumulated water to pass by opening the gates, and thus producing an artificial rush sufficient to carry all accumulations before it. The relative economy of the process, as practised in the Holborn and Finsbury division, and as compared with the hand cleansing, was stated as follows:—

	£	s.	d.
Washing away 6,688 cubic yards of deposit by board-dams (a process always performed preparatory to fixing and using the flushing apparatus)	644	12	7
Putting inside entrances and flushing gates .	1,293	0	0
	£1,937	12	7

The cost of removing these 6,688 cubic yards by hand would have amounted to £2,387. The preliminary cleansing and providing flushing apparatus were, therefore, effected at a saving of £449 7s. 5d. The current expenses of the two methods are thus stated:—

	£	s.	d.
Annual cost of cleansing 16 miles of sewers by hand	326	17	0
Annual cost of cleansing 16 miles of sewers by working flushing gates	106	0	0
Annual saving by flushing method	£220	17	0

The cost of this method, as subsequently practised under the new Metropolitan Commission of Sewers, has been reported as being about one-third that of cleansing by hand; thus 22,400 feet of sewers, in which the deposit varied from 6 inches to 3 feet 6 inches (in depth) were cleansed, and 3,386 double loads washed away at an expense of £500, which process, under the old system, would have cost £1,500.

The method of flushing is attended with one, and that a very serious, evil consequence, and the mischief of which is the greater in proportion to the force and velocity, and corresponding efficiency of the process. This is, the violent driving forward of the foul gases with which the otherwise vacant portion of a sewer holding stagnant refuse is

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usually filled. The flushing of the higher part of an extended line of sewer is thus frequently productive of a rising of these gases into the house-drains connected with the lower portion of the sewer, and any imperfection in the trapping of these admits the most noisome effluvia into the houses, while the streets are always poisoned with the gases thus driven up through the gratings and gully-holes. Sometimes, indeed, the flushing water is forced into the house-drains, and, of course, occasions a total suspension of the flow of the sewage in the reverse direction. Accordingly, we find that the process of flushing has been discontinued during the warm season, the very time when it is most needed as an artificial means of cleansing the sewers.

For the efficient cleansing of the streets and thoroughfares of a town two provisions are requisite, viz. an abundant supply of water for occasional application, when the self-supply of rain is suspended, and a complete arrangement of sewers through which to discharge all the surface-water when its purpose of cleansing has been fulfilled. For the supply of water, the system of constant supply affords the greatest facilities, giving an instant command of the required quantity.

It has been ascertained in London, that one ton of water is sufficient to lay the dust over a surface of 600 square yards of gravel or macadamized roads, or of 400 square yards of granite-paved streets. The average number of days per annum in which it is found, from twenty years' experience, to be necessary to apply water for this purpose, is about 120. The common charge for this work is at the rate of ¾d. per square yard for the season, the water being applied only once per diem, or £50 per mile of a main road. The common assessment per house for watering roads twice a day is £1 for the season. The cost of doing the same work by means of jets, supplied from the main water-pipes, is estimated at 5s. per house. At Nottingham, where the constant service of water is rendered, a charge

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of 7s. 6d. per annum is made for a single street plug, by which some of the proprietors of shops command a ready supply at all times for watering the street in front of their own premises, and often of the adjoining houses also.

The scouring effect of jets of water thrown upon the surface of the streets is far greater than when merely dropped or thrown from the perforated pipe of a water-cart. A single jet, supplied with a force equal to throw the water vertically upward to a height of 50 feet, will, directed at an angle of 45°, command an area of about 2,000 square yards, and this surface will be really cleansed by the process, whereas the mere distribution of the water, without pressure, wets without cleansing. The mud which is formed on the surface of the streets, during certain states of the weather, is well known to have an unctuous character, which resists all cleansing action less vigorous than that of jets of water under pressure.

The position of the main sewers beneath the streets of a town affords ready means of directly discharging the waste waters from their surface. The adaptation of the sewers for this purpose requires inlets, at intervals, fitted with iron gratings, by which large substances are prevented from passing into the sewers. These inlets and gratings being situated at the sides of the carriage-way, while the sewer is beneath the middle of it, they communicate by means of transverse drains or passages, which should be formed with sufficient declivity to prevent any accumulation of surface-water or road-sweepings beneath the gratings. The narrower the interstices between the bars of the gratings are the better. Very small spaces will suffice to admit the water with great rapidity, and also the mud which is formed upon the surface of the streets, and the narrow spaces are useful in preventing the admission of these matters during heavy showers with a force which might endanger the safety of the sewers.

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SECTION IV.

Classification of Buildings.—Constant Service.—Fittings.

The principal classes of buildings, as subjects for water-supply and drainage, are—1, dwellings; 2, manufactories; and 3, public buildings. Each of these admits of several subdivisions, which should be briefly enumerated, in order to indicate the extent to which they are recipients of pure water and contributors of refuse matters to the sum total of town sewage.

Dwellings are to be sub-classified according to the superficial area which they occupy, and the average number of residents whom they accommodate, and the arrangements to be provided for the joint purposes of supplying water and discharging sewage are required to be proportional to these two data combined. Upon the extent of area the quantity of rain-water will depend, and this has to be entered in the account in two ways: first, as affording an integral portion of the supply, and secondly, as contributing to the sum of the sewage. The principal datum will be the number of persons for whom water is required in each dwelling, and each of whom will yield an average share of the refuse to be removed. The calculations of water companies are usually based upon the rental paid for each house as an index to the consumption of water within it, and in this way they recognise an almost infinite number of classes. It is clear, however, that the mere rental furnishes no exact criterion of the number of occupants of a house. Nor would the number of rooms in a dwelling show this with much more accuracy. On the contrary, it is well known that houses of small rental and

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comparatively few apartments are frequently receptacles of a greater number of human beings than the more costly and capacious habitations of the wealthy classes. Nevertheless, it is a fact that, with the present habits of the poorer sections of the population, the rental is generally in approximate proportion to the quantity of water consumed —a fact to be accounted for only upon the recognised and deplorable principle that poverty and uncleanliness are mutual exponents and companions in the social condition of civilised beings.

The average daily quantity of water supply for each inhabitant of a town, has been taken at 20 gallons, and this quantity is supposed to be sufficient to allow also for an ordinary proportion of manufacturing operations, for the supply of public buildings, and for the extinction of fires. This estimate is founded upon the experience had in several towns in which the supply is considered adequate. Reserving the details of the appropriation of this quantity for the next section, we now refer to this general estimate as the datum upon which the proper supply of water to dwelling-houses should be provided, and as being at least approximately correct, if the service be constant, and proper inducements be offered to all classes to cultivate habits of cleanliness. We would, therefore, subdivide the first class of buildings or dwellings according to the average number of occupants of each, and provide the means of water-supply and sewerage accordingly.

The second class of buildings, or manufactories, including all consumers beyond households, admits of a subdivision according to the operations carried on. Chemical works, including those for dyeing, calico-printing, &c., rank high as consumers of water. Factories for the making of paper, distilleries, breweries, bakehouses, malting-rooms, slaughter-houses, stables, &c., also consume large quantities. Steam-engines are among the wholesale consumers.

Public buildings requiring constant service are to be divided according to the number of residents or persons to

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be supplied. Thus, union workhouses, prisons, lunatic asylums, &c., are to be provided at the minimum rate of 20 gallons per diem for each occupant. Baths and wash-houses require quantities in proportion to the maximum number of bathers and washers. Churches, theatres, and other places of public congregation are to be supplied for cleansing purposes according to the cubic contents of each building. In the baths it may be estimated that a bulk of water measuring 6 feet in length by 1½ feet in width, and 1 foot in depth will suffice for the ablution of each person. This quantity of water will equal 9 cubic feet, or about 54 gallons.

The necessity for constant service, great as it is in all buildings, is still more imperative in supplying those of which the demand is of a variable character. In certain seasons, when the occasion for repeated bathing of persons and cleansing of apartments is greatest, these duties require a much larger quantity of water than will suffice at other periods, and this demand of course increases in the same ratio with the number of persons and apartments to be supplied. Thus workhouses, prisons, and all public asylums vary considerably from time to time in the quantity of water required, and all methods of supply, short of constant service, and all provision for storage, fail in one way or another in securing the constant and unlimited command of fresh and pure water. Thus house-tanks, cisterns, and reservoirs, however capacious and well designed, serve to receive only limited quantities; and, if these be ample for all purposes, it follows that if the consumption be lessened the greater quantity of water will remain in a stagnant condition, to be added to but not replaced by the next delivery from the main. The lower body of water in the cistern will thus remain slightly changed, and stirred up only, and in this way a lower bed of impure water, surcharged and rendered heavy with deposited matters, gradually accumulates, suffering a slow diminution by the proportion of impurity which it imparts to each portion

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drawn off for immediate use. Pure or fresh water is by this arrangement put altogether out of the question.

In large public asylums, properly constructed, arrangements would be made for supplying a bath at least once a week for every inmate. For this purpose an institution having 1,000 residents would require weekly 54,000 gallons, or about 6,000 cubic feet of water. And if the supply be derived by a daily delivery, and the bathing be divided equally over six days in the week, a tank to hold the quantity for bathing only must have a capacity equal to 1,000 cubic feet, or of the minimum dimensions of 20 feet in length by 10 feet in width, and 5 feet in depth. The other purposes of cleansing would require (allowing 20 gallons per diem for each individual) 66,000 gallons weekly, or 11,000 gallons daily, and a tank to be daily emptied and refilled of the capacity of about 2,000 feet, or measuring, say, 20 feet in width and length, and 5 feet in depth. For contingencies provision should be made for about half this quantity in addition, and thus the entire capacity of the tanks should equal 4,000 cubic feet, or dimensions of 80 feet in length by 10 feet in width, and 5 feet in depth. And if the consumption one day be reduced one-fourth, and the tanks be not emptied before the fresh delivery—which it is practically impossible to effect—this quantity of stale water will remain in the lower part of the tanks, and each day's reduced consumption will tend to increase the impurity of the water, unless duplicate tanks be provided, and a large amount of water be wasted in their periodical cleansing.

In cases where the constant service of water cannot be obtained, and it consequently becomes necessary to provide cisterns for buildings, they should be so constructed and furnished as to combine the operation of filtering with the purpose of storing the water. For this purpose the best form of cistern will be that of which the bed inclines downwards, so that the discharge pipe may be inserted at the lowest point, and the water always drawn from that part

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of the cistern. The material used being commonly slate, the bottom may still be formed in a single slab for house cisterns (so as to avoid extra joints), declining in both directions. The filtering media, consisting of beds of sand and gravel of different degrees of fineness, will be arranged in horizontal layers, excepting the lower one, which will lie in the bottom of the cistern, and be dressed to a level on its upper surface. The head of the discharge pipe should be protected with a fine wire-gauze cap, to prevent the gravel washing into the pipe. Below this pipe another cistern for the filtered water should be provided of proportionate capacity, and if the process be too tedious to admit of the filtration of all the water used, that for inferior purposes may be drawn from a pipe entering the cistern just above the filtering beds.

The superior quality of rain-water in respect to its softness, as compared with water from all other sources, renders it exceedingly desirable, in an economical view, that all the supply derivable from this source should be carefully collected and preserved. In towns this water is commonly wasted, or at least allowed to subserve only the inferior purpose of assisting the flow of the drainage. Yet the quantity which might, by efficient arrangements, be commanded of this superior water is by no means insignificant. The roof of a house of the average dimensions of 20 feet square, presenting a plane surface of 400 square feet, receives at least 800 cubic feet of rain water annually, or about 4,800 gallons. If well-constructed and capacious gutters are provided, this quantity may be collected with little loss from evaporation, and will form a reserve stock for such special household purposes as it is peculiarly adapted for. This quantity should be immediately received in a filtering tank, and the best available method be adopted of purifying it from the carbonaceous matters with which it becomes saturated in passing through a smoky atmosphere and flowing over roof-surfaces covered with a deposit of similar impurity. An economical and well-devised

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apparatus for effecting this purpose, and applicable to private and public buildings of all classes, is a desideratum yet wanting in the economical supply of water.

All valves and other apparatus for regulating the admission and use of water in buildings are required to be constructed in the simplest and most efficient and durable manner. Complicated contrivances are utterly inadmissible to be intrusted to the ordinary carelessness and inattention with which these things are treated in separate households. Apparatus of costly construction will never receive the sanction of landlords, nor will temporary tenants incur the charge of expensive repairs, or devote regular attention to keep ball-cocks and similar appendages in working order. And in proportion as the rental of houses is less, these difficulties are increased. Landlords become more parsimonious, and tenants less interested and more neglectful. In this point of view the advantages of constant and high service are rendered more conspicuous than in its application to tenements of a superior class in which a higher rental enables the landlord to be liberal in the construction and appliances of the building, and the tenant shares his disposition to preserve their proper action in order to secure his own comfort and convenience.

If the rain-water be not collected for household cleansing purposes, it should at least be made as efficient as possible for scouring the house-drains.

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SECTION V.

Varieties of Manufactures and best available Methods of Draining.—Arrangement of Separate and Collective Drains.—Proportion of Area of Drain to Cubic Contents of Dwelling Houses.—Fall of Drains.—Mode of Construction.—Connection with Main or Collateral Sewers.—Means of Access, &c., &c.

The several operations carried on within a building devoted to manufacturing purposes should afford the data upon which to determine the extent of drainage required, but the most ready way of estimating the amount of refuse waters produced will be reached by assuming this to equal the supply of water rendered to the building. The application of the same rule to domestic buildings or dwellings admits of a more exact calculation as to the capacity of drains required, but these must all alike be governed by the principle, that ample capacity for immediate discharge is to be sought, with due regard to the fact that all passages for the conveyance of liquid or semi-liquid matters are efficient in proportion to the narrowness of the surface over which these matters are required to flow. This is one of the most important results which recent inquiries have established. Sewers and drains were formerly devised with the single object of making them large enough, by which it was supposed that their full efficiency was secured. But sluggishness of action is now recognised as the certain consequence of excess of surface equally as of deficiency of declination. A small stream of liquid matter extended over a wide surface, and reduced in depth in proportion to this width, suffers retardation from this circumstance as well as from a want of declivity in the current. Hence, a drain which is disproportionately large in comparison to

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the amount of drainage, becomes an inoperative apparatus, by reason of its undue dimensions; while, if the same amount of drainage is concentrated within a more limited channel, a greater rapidity is produced, and every addition to the contents of the drain aids, by the full force of its gravity, in propelling the entire quantity forward to the point of discharge.

There are four conditions which are to be regarded as indispensable in the construction of all drains from all buildings whatsoever. These conditions are :—First, that the entire length of drain is to be constructed and maintained with sufficient declivity towards the discharge into the sewer to enable the average proportion and quantity of liquid and solid matters committed to it to maintain a constant and uninterrupted motion, so that stagnation shall never occur; second, that the entire length of drain is to be constructed and maintained in a condition of complete impermeability, so that no portion of the matters put into it shall accidentally escape from it; third, that the head of the drain shall be so efficiently trapped that no gaseous or volatile properties or products can possibly arise from its contents; and fourth, that the lower extremity of the drain, or the point of its communication with the sewer, shall be so properly, completely, and durably formed, that no interruption to the flow of the drainage or escape shall there take place, and that no facility shall be offered for the upward progress of the sewage in case the sewer becomes surcharged, and thus tends to produce such an effect.

These conditions appear simple in their statement, and they may be regarded as self-evident necessities, yet an acquaintance with the details of house-drainage as commonly regulated reveals the fact that they have been generally neglected, and that, at the best, the attention they have received has been most unwisely crippled by considerations of cheapness in first cost at the expense of permanent economy and usefulness. Thus we know

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that house-drains are frequently laid with very imperfect fall, not sufficient indeed to propel the matters sent into them except with the aid of gushes of drainage-water; that they are often composed of defective and carelessly built brickwork with wide joints of sandy mortar; that the head of the drain is commonly untrapped; and that the entire formation is badly designed and defectively executed. We will endeavour to show the arrangements by which the efficient action of the separate drains of houses and other buildings is most likely to be secured.

The utmost practicable declivity being obtained in the direction of the drain, the efficiency of its action will be further much controlled by the construction adopted and the kind of surface presented to the sewage. Any roughness or irregularity in this surface will of course impede the passage of the sewage, and hence arises the necessity for the greatest care in the construction, whatever the material and kind of formation. The first step in the arrangement is, to collect the whole of the drainage to one point—the head of the intended draining apparatus, and the determination of this point requires a due consideration of its relation to the other extremity of the drain at which the discharge into the sewer is to take place. In buildings of great extent this will sometimes involve a good deal of arrangement, and it will, perhaps, become desirable to divide the entire drainage into two or more points of delivery, and conduct it in so many separate drains to the receiving sewer. The length of each drain being thus reduced to a manageable extent, the necessary fall will be more readily commanded, and the efficiency of the system secured.

The cost of constructing these minor works, and also the main sewers with which they are connected, is so enormously aggravated by the depth to which they are frequently laid in order to accommodate the basements of buildings, that, for the sake of economy, basement-drainage should either be altogether abandoned or so modified that efficiency shall never be sacrificed in a vain attempt to

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reconcile the depth of the basement with the position of the sewer. In arranging the drainage of buildings, therefore, the head of the drains should be kept at the minimum depth which will suffice to sink the construction beneath the surface. We have already expressed a conviction, that in a thoroughly perfect and economical system of town drainage this must be recognised as a leading principle, and under this conviction we could not be satisfied to admit the difficulty now experienced to be one which should encumber our proceedings so as to involve comparative inefficiency in action and extravagant costliness in construction and repairs.

Although it is not within our province in this place to discuss the governmental measures which would be required to authorise and direct such an adjustment of the details of private drainage as would be necessary to insure their conformity with the principle here advocated, we may be permitted to observe that this direction was, to a considerable extent, assumed and exercised by the old Commission of Sewers, who always declared their authority in prescribing the manner in which private drains should alone be allowed to communicate with the sewers under their jurisdiction. These prescriptions determined the rate of declivity, the relative levels, and the dimensions of the drains, and were enforced by the Commissioners' execution (by their contractors) of that portion of the work which joined with the sewers. The regulations enforced in the City of London (and which, from its independence of the new consolidated commission, are, it is supposed, still enforced) are based upon the following calculation, the stated principle being that "A house cannot be called effectually drained unless the water is taken away from the floor of its lowest story." *

* It should be borne in mind that this principle becomes impracticable if the lowest story of any house should, at the free will and option of its owner, have another "lower deep" excavated below it, a practice which has been indulged in in the formation of some of the leviathan warehouses in the City.

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	ft.	in.
"Take the least height which a basement story ought to be	7	0
Thickness of a timber flooring on sleepers	0	9
Covering of the drain, say brick flat	0	2½
Height of drain inside	0	9
Current of drain inside the premises, say, 1 inch to 10 feet for a house 50 feet deep	0	5
Current outside the house, *i.e.* in the street	0	3
Height of cross-drain above the bottom of main-drain, at least	0	6
	9	10½

"This would give (9 feet 10½ inches, or) 10 feet, at the least, depth from the surface of the street to the bottom of a main drain (of 18 inches diameter), and this may be fairly assumed as the least depth at which a private house of the most ordinary description can be effectually drained; but this considers it only as for the drainage of one house.

"When a series of houses, situate in a public way, inhabited by some who will use, and some who will not use, a drain fairly, is to be drained, the question has to be looked at differently.

	ft.	in.
"For a retail shop, in which the basement story is often used as a warehouse, it cannot be unreasonable to say that the story shall not be less in height than	8	6
Flooring	0	9
Covering of drain	0	2½
Height of drain	1	3
Current inside	0	5
Current outside	0	3
Height above bottom of common sewer	1	6
	12	10½

"As it may be said that a story of less height might do as a wareroom, and, in order to keep the calculation as low as it fairly can be kept, I would assume that the bottom of a common sewer ought not in any part to be less than 12 feet beneath the surface of the street."

We have thus quoted these calculations at length, in order that we may be enabled to refer to the details

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assumed without fear of mistaking the meaning of the official provisions of the Commissioners.

The common occupation of the basement stories of houses as kitchens and water-closets has made it appear desirable to depress the drains and sewers, in order to receive the refuse matter below the level of these basements; but as this object involves one or both of the evils we have pointed out, viz. deficient declivity and consequent stagnation in the drains, and a general system of sewers sunk so deeply in the ground that incomparable expense and difficulty are created in construction, access, and repairs, the purpose of basement-drainage should be abandoned, and practicable methods sought of delivering the entire drainage immediately beneath the surface of the ground. If, indeed, no practicable methods could be devised of doing this so as to render basement draining unnecessary, it must of course be admitted as part of the purpose of house-drainage, in order to avoid the sacrifice of the healthiness of human habitations, which we all readily admit as the final object of the art of draining towns and buildings.

The selection of the methods to be adopted for this purpose will be dependent mainly upon the internal arrangements of the building and the occupation of its lower apartments. In the first place, water-closets must in all cases be constructed above ground, or, at any rate, so nearly above, that the discharge shall take place within a foot or so of the surface. However valuable the ground-floor space of any premises may be, sufficient room may and always should be reserved for this purpose, as this level is the most desirable for the situation of these accommodations. If placed higher, they cannot be so readily aided with the sewage water produced in the domestic offices, unless these occupy a similarly elevated position; and besides this objection, is that of having an unnecessary length or extent of drains above the ground. The most desirable arrangement, therefore, is that which collects the entire drainage at or near the ground level, and there at

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once and immediately delivers it into the subterranean channels. If, however, it is in any case unavoidable that the kitchen and similar domestic offices are situated in the basement of the building, it will be still equally imperative that all the sewage water shall be delivered into the drain at or near the ground level. No sink or other apparatus for discharging refuse water should be retained in the basement, and the extra labour of carrying this water up to the surface level, or head of the drainage, must be incurred as the penalty of this misconstruction or misappropriation of the building.

These arrangements, although involving expense in the alteration of some of the existing buildings in towns, are not to be magnified into impracticabilities. As essential parts of a general system conducive to the health of the entire population, they should be commanded and enforced by adequate public authority, and carried into immediate effect without favour or evasion. And in the construction of new buildings, they should be regarded as imperative general orders, sanctioned by the public well-being, and, if necessary, to be obeyed under official superintendence. The truth of principles and advantage of modes of action, established by experiment, should command their adoption without opposition, from the prevailing squeamish reluctance to interfere with private arrangements, which, be it remembered, are, if misdirected, really in these matters public nuisances.

The keeping of the basement itself of a building dry by draining is not, we submit, to be acknowledged as a proper purpose of a correct general system. Sufficient and sound construction are alone needed to maintain basement stories of any depth in a perfectly dry condition, if all sewage and rain-waters are, as they should be, collected and discharged into the sewers before they reach the basement. The draining of the surrounding subsoil to the entire depth of the foundation of a building is a want which cannot arise, if the entire structure up to the ground level is waterproof,

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which we contend it should be; the means of effecting this by the materials now at our command being of economical and certain application.

Discarding brickwork and all similar constructions of small parts, as unsuitable for obtaining the impermeability and smoothness of internal surface which are especially required in small drains, the current in which is often reduced to a very small quantity of liquid or semi-solid matter, we are led to seek some tubes or pipes which shall require only annular joining at distant points and thus admit of the regularity of surface which is so necessary to assist the passage of the drainage. The stoneware is now offered as a superior material for this purpose, admitting of much greater economy than iron, and being entirely free from the chance of corrosion and permeability. By glazing the interior surface, moreover, tubes of this ware are made peculiarly suitable for adoption in forming drains; and carefully made socket joints laid in the direction of the current are cheaply executed, if moulded conically and luted with a little cement of best quality.

The size of the drain-pipes has to be graduated according to the quantity to be passed through them, limited in the minimum extreme so as to avoid stoppage from the excessive bulk of the sewage matters, and in the maximum extreme so as to obtain all the rapidity of progress of which a small stream of water is capable, retarded by the friction of the surface over which it passes. For moderate-sized houses, say of eight rooms, and holding some five or six persons on an average, a tube of 5 inches in diameter will suffice for the house-drain. The area of the drain may be proportional to the cubic contents of the house, but if so, in diminishing ratio. That is, if a 5-inch pipe will be large enough for an average-sized house, a pipe of double the area of such a pipe will not be required for a house of double the cubic contents, or holding double the average number of persons. A 6-inch pipe, laid with sufficient fall, will be ample for the most capacious private house. And

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from 9 to 15 inches will, under a similar condition, be sufficient to serve the average drainage of factories and other large consumers of water.

The trapping of the head of the drain, so as to prevent the ascent of smell and impure gas from the drain into the building, is the next indispensable requirement in the draining apparatus. So many contrivances have been applied for this purpose, that we will not attempt to make a selection; and it is beyond our limits to give any general list or detailed description of them. Simplicity of construction and permanence of action are, of course, required, with the least original outlay at which these qualities can be obtained. If only one water-closet is to be provided for, it will be desirable to gather the discharge from it and from the house-sink, &c., into one trap at the head of the drain. If two or more closets are to be served, so many separate traps will sometimes become indispensable. But for every separate inlet to the drain, which is equally an outlet for smell and gas, an efficient trapping apparatus of some kind is required.

The lower connection of the house-drain with the public sewer is the last point of importance to which we have to allude. A perfect construction of this portion of the work has always been recognised as an essential feature of good drainage. The level of the bed of the drain must be kept as high as possible above that of the receiving sewer. If the sewer be also constructed of the glazed stoneware piping, lengths of it may be introduced at convenient intervals, having outlet sockets for receiving the ends of the house-drains, and those being slightly tapered or conical in form can be readily jointed.

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SECTION VI.

Water-closets: Arrangement and Construction. — Adaptation to various circumstances.—Combined Arrangements for Efficient House Drainage.—Miscellaneous Apparatus and Contrivances.

The best position for a water-closet in any building is that in which all the waste water shall be made the best use of in scouring the contents directly through the pan of the closet, and propelling them forward through the private drain into the common sewer. And since the matters discharged into the closet will be, if the house-drain is reserved for its proper uses, more solid and less readily conveyed than the other sewage matters, it will, moreover, be desirable to place the closet as near as possible to the point at which the drain discharges into the sewer. The velocity and force of the liquid sewage are increased at the lower or sewer end of the drain, and its effect is thus augmented in scouring away the contributions of the closet. But if this preferable position cannot be commanded for the closet, it must, at any rate, be so situated with regard to the head of the drain and the inlet for the liquid sewage, that these shall be behind or above it. When the closet and the house-sink are near to each other, the water from the latter may be conducted directly into the trap or basin of the closet, and thus secure at once a rapid discharge of its contents and a constant supply of liquid to preserve its action and efficiency.

The rudest form of domestic accommodation or open privy over a cesspool is a contrivance which deserves notice only on account of its several imperfections, and which

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will, it may be hoped, be soon reckoned among the obsolete mistakes of our forefathers. These cesspools are sometimes mere pits or holes excavated in the ground, and the contents of course rapidly permeate the surrounding soil, by which process pits of this kind frequently are found to drain themselves, the perviousness of the material permitting the escape of the sewage, so that little accumulation takes place within the pit itself until the whole neighbourhood becomes fully saturated with the drainage, which will then ooze through and appear upon the surface, or find its way through some defective foundation, and poison the basement of an adjoining building. Constructed cesspools formed with brickwork of substantial quality will prevent this saturation in proportion as their walls are carefully and imperviously built. The matters daily discharged into these depositories accumulate, and their decomposition is constantly proceeding and engendering gases of the most noisome and pestilential kind. The open privy formed over a pit of this description affords an outlet for the escape of these gases, which are thus regularly supplied to the building above or adjacent to the closet. If a trap or water basin and pan be applied to this privy, so that the pan dips into the trap, the escape of effluvia may be prevented so long as the trap is kept supplied with water. The supply of water for this purpose will, however, considerably augment the bulk of the sewage, and necessitate cleansing much more frequently than otherwise, unless some defect in the joints of the work afford a passage for the liquid matters in the surrounding strata, or a communication be afforded with a drain. In this latter case of combination of a cesspool with a drain, a waste pipe may be laid from the former into the latter, so that the contents of the cesspool shall always be maintained at the same quantity and depth; the trap may then be dispensed with by attaching a vertical pipe to the lower part of the pan, so that this pipe shall dip into the sewage, and being thus constantly kept below its surface, no gas can pass upward through the

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pipe. The cost of the pan or basin and pipe required for this contrivance, if of stoneware, will not exceed 13s. in addition to that of a common privy, and its advantages in preventing the escape of effluvia are obvious. The simplest and cheapest form of trap and basin is that in which they are formed in one or two pieces of the stoneware, and may be purchased at about 7s. 6d. together. Allowing 5s. 6d. for the fixing, and also providing and fixing a short length of pipe of the same material to connect with the trap so as to dip into the sewage, this complete trapped apparatus may, at a cost of 13s., be added to a common privy over a cesspool, so as to prevent to a great extent the escape of effluvia into the house or adjacent building.

The great importance, however, of avoiding all sources of unwholesome and offensive effluvia, and of preserving the foundations of the buildings and the substrata of the soil of a town in a dry and clean condition, creates a severe necessity for relinquishing cesspools, and all receptacles for sewage within or connected with all buildings and places whatsoever, except those to which it is conducted for the purposes of collection and treatment. The sole purpose of all house apparatus of water-closets, sinks, and drains, and of all public constructions of branch or tributary sewers and main sewers, should be that of affording a passage for the conveyance of the refuse waters and other matters produced in a town. This conveyance should be immediate, every particle committed to the entire ramification of passages being preserved in ceaseless motion until it arrives at the final collecting place.

Discarding cesspools upon these grounds, we are at the same time led to the principle which should govern the whole of the details of house-draining apparatus, which should be so arranged and combined as to afford the fewest possible inlets for effluvia from the matters committed to the drains, and to make the total of the liquid refuse useful in advancing the current within the drains. The position of the water-closet being determined, it becomes desirable

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to select the most economical and efficient construction for it, and for the apparatus connected with it.

We have already stated that the head of the drain, and every inlet to it, requires to be fitted with a trap to prevent the escape of effluvia, and this will equally form an indispensable part of the closet apparatus. The perfect action of the trap will demand a means of supplying water on each use of the closet, and although all possible advantage should be taken of the house-sewage water in promoting the action of the drains, a separate and constantly-commanded source should be provided for this purpose. If the supply of water to the house or building be rendered upon the constant-service system, a mere tap will be sufficient to afford the means of discharging a volume of water through the trap of the closet. If the water be supplied upon the intermittent system, a cistern or reservoir of some kind, provided for the house supply, must be made to communicate with the pan of the closet by a pipe with a valve and apparatus for working it. For general use it is especially desirable that economy and simplicity be combined in the whole of the apparatus of the closet. Delicacy of adjustment, requiring a complicated arrangement of parts, and a corresponding costliness of construction and repairs, and carefulness in management, is inadmissible in a design adapted for general adoption; and combinations of levers and cranks, liable to accidental derangement and injury by roughness of treatment, are therefore to be avoided as much as possible. The position of the cistern in relation to the closet will affect, in some degree, the force and efficiency of the volume of water discharged on each occasion; and, if the supply of water to the building be constant, the service-pipe should be so conducted over the closet that the tap can be conveniently placed for admitting the required quantity to the pan. If the supply is obtained from a house-cistern, this must, of course, be placed above the pan, and at such elevation that the water may acquire a sufficient impetus to flow with rapidity.

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The glazed stoneware basins or pans, with syphon-traps combined, before referred to, are the most economical and effective for general purposes. These are made in several forms, viz. with the pan and trap in one piece, and adapted to communicate either with a vertical or a horizontal drain; with a separate trap, having a screwed socket on the head in which the lower part of the pan is received, being formed with a collar and screwed end; or, as a somewhat more complicated arrangement, consisting of a trap with a flanged head and a separate dip pipe having a projecting flange about its mid-length, and a spreading mouth above, into which the lower part of the pan is fitted with cement. The dip pipe, extending downwards into the trap, below the level at which its contents flow out, is secured to the head of the trap by bolts passing through the holes in the flanges. The reason for making the pan separate from the dip pipe would appear to arise from a difficulty in forming them together with the wide projecting flange so as to give sufficient steadiness to the pan above. This latter form was designed especially for prison use, under circumstances which do not allow of any fixed seat or framing above to which to secure the pan. The previous forms are found to answer all purposes in cases where this kind of support is afforded, and are preferable for their fewer number of parts. The pan in each of these forms of construction is provided with an aperture and an inlet at the upper part, having a socket to receive the water-pipe. They are retailed at the price of 7s. 6d. each, and recommended by the present authorities in drainage matters.

The combined arrangements for efficient house-drainage comprise, besides the means of adequate water supply, as already explained, the water-closets, house-sinks, and drains in which the matters committed to the closets and sinks are conveyed and delivered into the public sewers. And if the rain-water falling on the roof of the building and on the yard or space attached to the house, is not applied to any other purpose, it will have to be conducted into the

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drain to be discharged with the sewage. These waters being the purest of the contents, should be received as near as possible to the head of the drain, and made to traverse its entire length, and thus exert all the cleansing action of which they are capable. The house-sink or place at which the ordinary waste water of the household is discharged should communicate with the drain at a subsequent part of its course, and the closet be so placed that its contents shall traverse a minimum portion of the drain, thus reducing the liability to the escape of effluvia, and deriving the greatest scouring force from the accumulation of the rain and house waters. The drain being formed as a complete and impervious channel receiving the entire sewage and waste waters of the premises, made easy of access and examination, and provided with traps at every opening or inlet for receiving the drainage, may be graduated in size from the one extremity to the other, and, if of considerable length, it may be provided at intervals with self-acting valves or traps to prevent the possible return of any matters, waters, or gases from the lower towards the upper end.

Self-acting valves or traps are constructed of the stoneware, and the valves being hung at a slight inclination, and well fitted with a rim on the meeting surface, they remain closed against any retrograde movement of the sewage or gases, but are readily opened by a slight force of water in the outward direction of the drain. Sink traps are also formed of this material, with perforated heads or covers, and syphon bends below, which, remaining filled with the drainage water, prevent the escape of any effluvia from the drain into which they give access.

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ADDITIONAL SECTIONS ON DRAINAGE OF TOWNS.

By D. K. CLARK, M.Inst.C.E.

I.—Disposal of Sewage, Systems, General Principles.

Disposal of Sewage.—Systems.—General Principles.—Steep Gradients.—Sewer Ventilation.—Gullies.—Flushing.—Tank Sewers.—Disposal of Rainfall.—Typical Examples of Town Drainage.

How to dispose of the sewage of towns is a question that has not yet received its final solution. The various systems that have been tried or adopted may be classed generally as follows:—1. Treatment with chemicals. 2. Application of sewage to land, including irrigation and intermittent downward filtration. 3. The dry-earth system. 4. The Liernur or pneumatic system. 5. Seaboard and river outfalls.

The first system seeks, by the admixture of chemicals, to precipitate the dissolved and suspended matter of the sewage, and render it available as manure. The lime process is amongst the earliest of the chemical methods of treatment in England. It was adopted forty years ago at Leicester, but has since been abandoned. It was adopted at Birmingham, where the effluent is discharged into the Rea or the Tame, or is disposed of by irrigation. Five hundred tons of sludge is produced daily, and is for the most part dug into drying-beds covering a large acreage, which is being continually extended. The result of the process, as a sanitary measure, is a failure. Other systems of chemical treatment have been tried, and they do not appear to have resulted successfully.

Given a seaboard town, the proper destination of the

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sewage is the sea. Sewage must for the present be regarded, as Sir Joseph Bazalgette well puts it, as an enemy to be got rid of, and not as a friend to be courted and turned to account. No doubt sewage is an article from which one would expect a return; but, for various reasons, it is exceedingly difficult to turn it to profitable account. There is "the water difficulty." Whilst it is of the greatest advantage to towns to have an ample water supply to carry off the sewage, that ample supply forms one of the great difficulties in dealing with it at its outfall. There is "the land difficulty." In the neighbourhood of large towns land can only be obtained at a great cost. These two difficulties, added to the necessity for purifying, stand in the way of what otherwise might be a most successful mode, not only of purifying sewage, but also of applying it to profitable account, namely, by means of irrigation.

The object in view is to remove the sewage from the town in such a way as not to be offensive to sight or to smell, and to improve the health of the people, "on the principle," to quote Sir Joseph Bazalgette again, "of diverting the cause of mischief to a locality where it can do no mischief." Towns situated on the sea-coast, or within the tidal range of rivers, should avail themselves of the means of outfall thus presented, as affording the most economical and efficient means of dealing with their sewage; laying intercepting sewers, acting, as far as possible, by gravitation, and care being taken in the selection of outfalls. Towns lying on the sea-shore, where there is sufficient fall, have simply to carry out their sewers below low-water line, as was formerly done at Brighton. But without sufficient fall there is a liability to stagnation and deposition of silt. On steep gradients, on the contrary, ventilation must be specially provided for, to prevent the ascent of sewer-gases to the higher localities. In fact, as a principle of universal application, a system of sewers over an entire town should not be laid down without, in

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the first instance, providing as part of the scheme, for the fullest and freest ventilation, at all parts of the town, generally most necessary at the upper and higher levels. Sewage-gases are lighter than atmospheric air, and flow upwards, while the sewage itself flows downwards, and as the velocity of discharge of sewage-water downwards is in proportion to the gradient of the sewer, the flow of sewage-gases upwards is also in proportion to the gradient. Therefore a town that has naturally steep gradients requires the fullest means of ventilation; and so far from its being easy to sewer such a town, if proper means are not taken to provide for ventilation, the engineer may leave the town worse than he found it. Sir Robert Rawlinson states that, within his own knowledge, disease has broken out in well-sewered districts, which was traced to a connection of house-drains with unventilated sewers; and in such cases the highest portions of the towns suffered the most severely. When the gradient, he says, is steeper than 1 in 200, and a sewer is, say, one mile in length, it should be divided by steps or falls, and there should be a flap-valve upon the upper or higher discharging end of the sewer, with at least two ventilating grates at that place, to insure thorough ventilation. The system of ventilation he has adopted, in conformity with these views, is shown in Fig. 81. The manhole-shaft is closed with a manhole-cover, by removing which access may be had to the shaft when desired. The sewer-gas is compelled to rise through two or more charcoal screens or filters before passing into the ventilating chamber. By a slide at the bottom of the chamber deposit can be removed. A modification of this system is shown in Fig. 82. Sir Robert comments on the difference in the death-rates of towns having steep gradients and towns having flat gradients. Some of the former had high death-rates, and some of the latter had low death-rates. Portsmouth, which is comparatively flat, with its barracks, constantly appears in the Registrar-General's returns as having one of the lowest death-rates. Here the sewage is discharged with great

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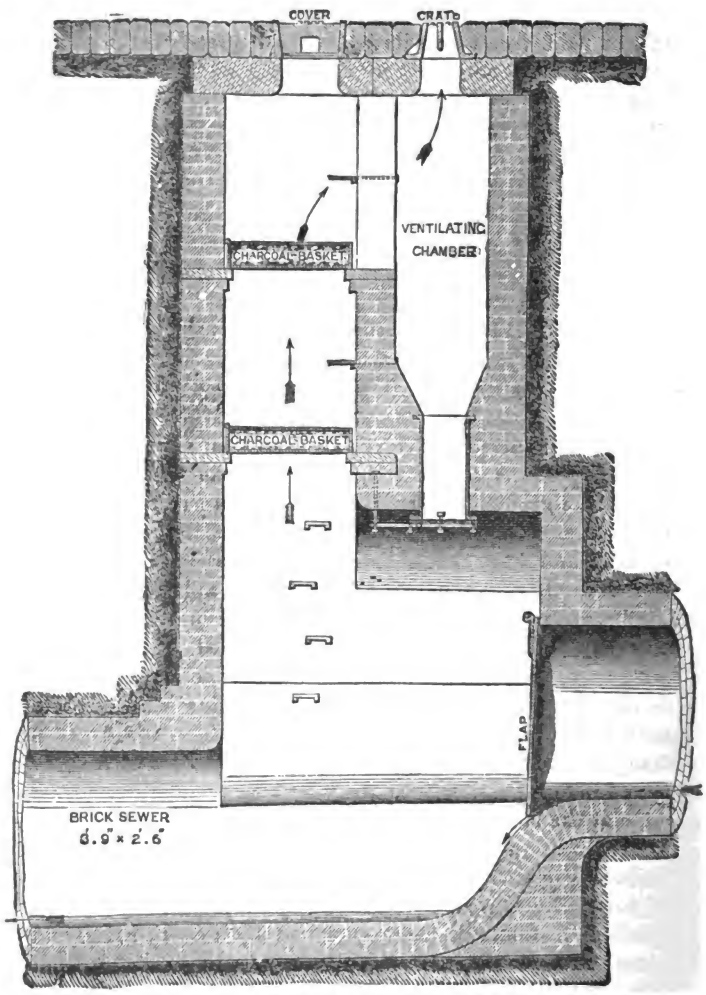

Fig. 81.—Ventilation of Sewers. Sir Robert Rawlinson's System.

velocity into the sea. Hull, also, with its flat site and un-

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ventilated sewers, frequently stands very low. Liverpool, many years ago, when the sewers were not ventilated, had a death-rate notoriously high. But after they were ventilated, under Mr. Deacon's management, the death-rate from those zymotic diseases which are generally believed to be directly influenced by sanitary improvements, showed a marked reduction. The years 1870 to 1874, inclusive, were those immediately preceding improvements made in

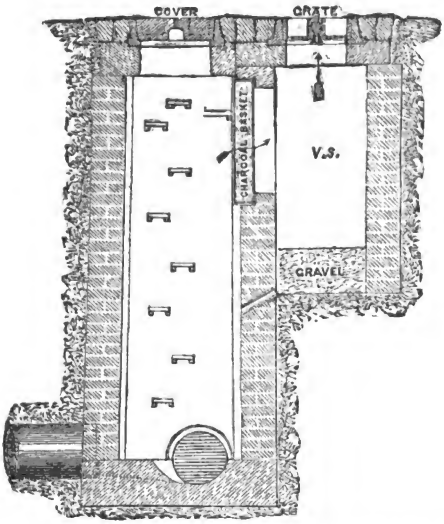

Fig. 82.—Ventilation of Sewers, by Sir Robert Rawlinson.

the sewers, including their ventilation, and compared with the succeeding years, showed a diminution of the zymotic death-rate of 46 per cent. Comparing Liverpool, a hilly town, with Manchester, a flat town, it appears that, for the decade 1870—80, the death-rates were identical.

The peculiar liability of hilly towns to the inroads of sewer-gas by ascension, points to the necessity of dividing the sewers into zones, breaking the steep gradients at

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various contour-lines, stopping the gas at such places, and not permitting it to rise to the upper gradients. Sir Robert Rawlinson instances the case of Leeds, where, several years ago, there had been a large death-rate in the higher and better districts. He held an inquiry, and returns were produced showing the money expended year by year upon the sewers. The death-rate returns for the same years were also produced; and he pointed out that in proportion as money had been expended in sewering Leeds, the death-rate had been raised, especially in the higher class of houses in the suburbs. There was not a single ventilator on the sewers. The main outlet was a sewer about 6 feet or 7 feet high, and 4 feet or 5 feet wide, running parallel with the river for more than a mile, and having its mouth wide open for air to blow into it. As the main drains, unfortunately, were connected directly with the sewers, there was nothing to cut off the flow of sewer-gas into the houses that had been drained. Hence the high death-rate in the town. Such a difficulty is one that can be readily overcome, and there are great advantages in having sewers with good falls and steep gradients.

In the case of an intercepting sewer laid at Aberdeen, it is found that, during the period when the tidal valve is closed and the sewer has no outlet, the noxious gases generated in the main culvert find their way up the various drains and subsidiary sewers into the higher part of the town. An attempt had been made, partially successful, to remedy the evil by placing metal valves on the outlets of sewers entering the main culvert. These open when a slight quantity of sewage collects behind them, but generally they are closed. At Brighton, situated similarly to Aberdeen, sludge is deposited, and sewer-gas is constantly given off.

Sewer-ventilation is affected by change of weather, of wind, or of temperature. But the most active agent in driving out foul air, and replacing it with fresh air is,

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perhaps, the variation in the flow of the sewage itself. When a sewer is flushed foul air is discharged at the ventilators, and, as the water subsides, fresh air is drawn into the sewer. The expulsion of sewer gas, though objectionable, particularly in narrow streets, is safer for the public health than if the gases should find their way insidiously into dwellings. Ventilating pipes, carried above chimneys and windows, should be adopted in narrow streets and thoroughfares instead of ordinary manholes.

In the construction of gullies certain principles should be observed. They should be made so as to prevent road-detritus from entering the sewers, and to arrest the escape of noxious effluvia, while at the same time they should provide for the admission of a downward current of air, to aid in the ventilation of the sewer. With untrapped and imperfect gullies this downward current exists; but they also permit the foul air to escape through the same channel. The gullies in Preston, Fig. 83, are an instance of this, as unless there is a sufficient quantity of water in the reservoir there can be no trap, for, when the water is evaporated below the level of the syphon-dip, the gully is no longer trapped, and the sewer is in direct communication with the upper air. The same state of things exists in Derby and Leicester.

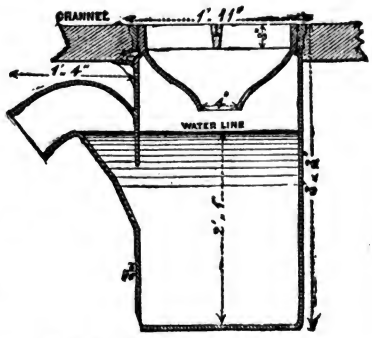

Fig. 83.—Gully-trap, Preston.

There are engineers who argue by their practice that no special ventilation is required with well-constructed sewers. For instance, in the sewerage of Dundee, a hilly area, no

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ventilation whatever has been provided. It is argued that there cannot be any generation of gases from putrid matter in the drains, as all putrefiable matters are carried rapidly through the drains to the river, and then to the sea. It is not denied that gases do to some extent exist in the sewers; but the gases, it is said, are not present in such volume as to overcome the ordinary traps, and they are, it is maintained, carried off by the flood waters. The only deposit habitually left in any of the sewers or drains is sand. This, on being taken up, does not emit perceptible odour, and when closely examined has all the appearance of ordinary river sand. "It is only when sewers are badly constructed," says Mr. Fulton, who designed the sewerage of Dundee, "as regards their form and water-run, that putrid matters are retained in them to poison the surrounding atmosphere and to bring disgrace upon the very name of drainage. No sewer under 10 feet in vertical dimension ought to have an invert of greater than 9 inches radius, and a 6-inch radius is quite large enough for the radius of the invert of any ordinary sewer. When the sewage is confined to such a small compass as this, its scouring power is very great, and if means can be taken to have the invert-blocks laid in a straight line, with such fall as may be available, it will be found that, although the fall be slight, little silting will take place, and that it will consist of sand only. No ventilation, therefore, is requisite with well-constructed sewers. It is only when the scouring effect of the sewage is lost, by constructing sewers with flat bottoms, that such is needed."

The health of a district depends, in the first place, of course, upon the proper arrangement of the sewers; but it also depends upon their proper ventilation, and on the effectual cutting off of house-drains from all direct communication with the sewers.

When sewers are constructed with falls insufficient to keep them self-cleansing, flushing is resorted to. Flushing by means of flushing-gates or by storing up the sewage

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is unsatisfactory in its results. Water so backed up causes a deposit behind it, and when it is let go it simply causes a flush for a short distance.

Flushing is effected under more favourable conditions when road-detritus is not carried into the flushing sewer. The self-cleansing power of the sewer is better. That the sewers should also be made water-tight is always essential for effective flushing, for with the escape of the sewage into the surrounding soil the effect of the operation is much reduced. The injury done to property by undermining consequent upon leaky sewers, is great in proportion as it is hidden and unknown. Damp walls, rotten joists, and unwholesome emanations are no doubt frequently attributable to this cause.

Tide-locked sewers have a strong tendency to silt up. They are usually made of the same sectional area as would have been adopted if they had not been tide-locked; and silting takes place until the sectional area is reduced to the extent necessary to gorge the sewer, create an artificial head, and thus to increase the velocity at low-water to the scouring point. It is true that during heavy rainfall this silting tends to cause flooding by backwater. But if, argues Mr. G. F. Deacon, the sectional area had been, in the first instance, made but little greater than the sectional area of the silted sewer, the silting would never have taken place, and the reduced sewer would have discharged more water than the original silted sewer. He has applied these considerations in practice. He reduced the tide-locked portion of a large outfall sewer to between one-half and one-third of its full section, with the result that silting was entirely obviated and that greater discharging power was obtained.

A contrast between the operations of a constant discharge and an intermittent discharge is given by Mr. John Grant in the case of the Metropolitan Main Drainage at Barking Creek on the north side, and at Crossness on the south side of the river Thames. Both of the outfall sewers,

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which are afterwards described, have been laid with a fall of 2 feet per mile. The three culverts forming the outfall sewer from Abbey Mills to Barking were built on a high level, and they have at all times a clear discharge into the reservoir at the outfall. With regard to the sewer at Crossness, it is exceedingly difficult to keep the lower length of three miles of it clear. As soon as it is cleansed it begins to get foul again, because the outflow is periodically choked; the sewage flows down into ponded-up deep water, incurring a great tendency to form deposits.

"Tank-sewers," so called, are constructed for low outfalls, for the collection of the sewage and the deposit of silt, &c. The discharge takes place on the ebb tide, and the sewage is entirely got rid of. If twice every day the sewers are tide-locked when the subsidence in the sewers takes place, Mr. Baldwin Latham argues that a large volume of fresh air is immediately drawn into them, "so that virtually the rise and fall of the sewage in a tide-locked sewer acts like a pair of bellows, making the ventilation perfect. Fresh air is drawn in at one period of the day, to be expelled when mixed with a small quantity of foul air from the sewage at another period." Mr. Lemon also intercepts washings and deposits in tanks at the outfall because he discourages flushing into a river; the mud deposited by the outfall-sewer being pumped out by a mud-pump or other means. Mr. Latham appeals to the records of public health in the question of tank-sewers versus continuous discharge. In the report of the Registrar-General on the health-resorts, published in June, 1879, it was shown that in Llandudno, where he had adopted a tank-sewer during the previous three months, there had not been a single death from any zymotic disease. In Worthing, also, where Mr. Rawlinson had adopted the tank-sewer, the zymotic death-rate was much lower in the same period than at Torquay, where an intercepting system with continuous discharge was adopted. The less apparent healthfulness of Torquay is explained by the fact

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that that town is the resort of invalids; so that a higher death-rate does not necessarily prove unhealthfulness.

The most general solution of the problem of sewage-disposal is to be found in the treatment of sewage by chemical means, resulting in the precipitation of the solids and part, at least, of the organic impurities; the effluent being discharged into the sea or the nearest river, and the precipitated matter, or sludge, being deprived of nearly all of its moisture by treatment in filter-presses, and reduced to the condition of hard cakes of small volume, readily transportable. When ready means of transport by water are available, the sludge may be carried off to the sea in barges and discharged there, without any treatment in the filter-press. The Metropolitan Board of Works have decided to give this system a trial. They have also experimented with filter-presses at the Crossness station, with satisfactory results. The filter-presses employed are those of the Radial Filter-Press Company, of which Mr. D. K. Clark is the Engineer; and of Messrs. Johnson and Co.

How to dispose of the rainfall is a question of some difficulty, which has given rise to much diversity of opinion, from the fact that, though in itself harmless, and even advantageous to the river, it sometimes falls suddenly in large quantities. These considerations have induced many persons to advocate that the rainfall should not be allowed to flow off with the sewage, but should be dealt with by a separate system of drains. This theory is, as a general rule, impracticable, involving a double set of drains to every house, and the construction and maintenance of a second series of sewers to every street. But for the special purpose of irrigation with sewage, the separation of the rainfall from the sewage proper is of material importance.

The application of the principles of town-drainage, thus generally enumerated, is variously illustrated in the typical examples of town-drainage, following:—

The main drainage of London comes first in order, as a magnificent instance of successful drainage, in which the

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sewage is intercepted in zones, by intercepting sewers on each side of the river Thames, concentrated in single outfalls, and discharged into the river at each side, many miles below London.

The drainage of Torquay is another case of the interception and collection of the sewage at two levels, combined in one outfall into the sea, outside the bay, where the sewage is finally dissipated and absorbed.

The drainage of Brighton is another case of interception of sewage, where flushing operations have to be resorted to to clear the sewers, in consequence of the submergence of the outfall by the tide and the suspension of the outflow, with the attendant precipitation of silt.

The drainage of Newport, Monmouthshire, is constructed with four outfalls into the River Usk, where the great width of the river, and the extraordinary rise of the tide, render the volume of sewage an insignificant consideration.

The drainage of Dundee is an unique example of sewers without ventilation. The sewers are kept clear by flushing, the motive power of which is derived from the temporary turning of the sewage from one sewer into another.

The drainage of Hamburg supplies an excellent example of successful flushing of sewers, where the gradients are of sufficient steepness.

The drainage of Paris is designed on the principle that the solid excreta should not be admitted into the sewers, which are designed only for carrying off rain-water and household water. All the sewers are accessible to and traversable by men. A thorough system of cleansing the sewers is in constant operation.

The following types of town-drainage have been designed with a view to the utilisation of the sewage by irrigation.

The main drainage of the Wandle Valley is effected by gravitation. The scheme is one of separation, in which the sewage proper is collected separately from the rainfall. The sewage is treated with lime for the precipitation of

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sludge, which is filter-pressed, whilst the effluent is turned on land for irrigation.

The drainage of Abingdon, also, is arranged for the separation of rainfall and road detritus from the sewage proper. The sewers are flushed at regular intervals, and the sewage is pumped on the land for irrigation and filtration, whence the effluent passes into the River Thames.

At the sewage works of Abergavenny, the whole of the sewage is delivered by gravitation upon the land for irrigation and downward filtration.

In the drainage system of Adelaide, South Australia, the sewage is kept separate from rainfall, and is delivered on a sewage farm.

II.—The Main Drainage of London.

The objects sought to be attained in the execution of the main-drainage works were: the interception of the sewage, as far as practicable, by gravitation, together with so much of the rainfall mixed with it as could be reasonably dealt with, so as to divert it from the river Thames, near London; the substitution of a constant for an intermittent flow in the sewers; the abolition of stagnant and tide-locked sewers, with their consequent accumulations of deposit; and the provision of deep and improved outfalls, for the extension of sewerage into districts previously, for want of such outfalls, imperfectly drained. The works for this purpose were designed and laid out by Sir Joseph Bazalgette, the engineer to the Metropolitan Board of Works.

According to the system which it was sought to improve, the London main sewers fell into the valley of the Thames, and most of them, passing under the low grounds on the margin of the river before they reached it, discharged their contents into that river at or about the level and at the time of low water only. As the tide rose it closed the outlets, and ponded back the sewage flowing from the high

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grounds. This accumulated in the low-lying portions of the sewers, where it remained stagnant, in many cases for eighteen out of every twenty-four hours. During that period the heavier ingredients were deposited, and from day to day accumulated in the sewers; besides which, in times of heavy and long-continued rains, and more particularly when these occurred at the time of high-water in the river, the closed sewers were unable to store the increased volume of sewage, which then rose through the house-drains, and flooded the basements of the houses.

The effect upon the Thames, of thus discharging the sewage into it at the time of low water was most injurious, because not only was it carried by the rising tide up the river, to be brought back to London by the following ebb tide, there to mix with each day's fresh supply, but the volume of the pure water in the river being at the time at its minimum, rendered it quite incapable of diluting and disinfecting such vast masses of sewage.

In the system now adopted these evils have been removed by the construction of new lines of sewers laid at right angles to the pre-existing sewers, and a little below their levels, so as to intercept their contents, and convey them to outfalls into the river fourteen miles below London Bridge. As large a proportion of the sewage as practicable is by this means carried away by gravitation, and for the remainder a constant discharge is effected by pumping. At the outlets, the sewage is delivered into reservoirs situated on the banks of the Thames, and placed at such a level as enables them to discharge into the river at or about the time of high water. By this arrangement the sewage is not only at once diluted by the large volume of water in the Thames at high water, but is also carried by the ebb tide to a point in the river twenty-six miles below London Bridge, and its return by the following flood tide within the metropolitan area is effectually prevented.

The questions that demanded solution preliminarily were these: 1. At what point and state of the tide can the

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sewage be discharged into the river so as not to return within the most densely inhabited portions of the metropolis? 2. What is the minimum fall which should be given to the intercepting sewers? 3. What is the quantity of sewage to be intercepted, and does it pass off at a uniform flow at all hours of the day and night, or in what manner? 4. Is the rainfall to be mixed with the sewage; in what manner and quantities does it flow into the sewers, and is it also to be carried off in the intercepting sewers, or has it to be provided for? 5. Having regard to all these points, how are the sizes of the intercepting and main drainage sewers to be determined? 6. What description of pumping engines and of pumps are best suited for lifting the sewage of London at the pumping stations?

With respect to the first question, the position of the outfalls and the time of discharge into the river were arrived at by placing floats on the river, and observing the range of oscillation with the flow and the ebb. The experiments proved that it was essential to take the discharge as far down as Barking Creek, as already stated. A practical limit to the distance of discharge was imposed at the north side of the river, to secure the advantages of a discharge by gravitation, a sufficient fall in the sewer being maintained; and at the south side, in order to preserve, as a safety outlet, a discharge into the river at low water by gravitation, in case of accident to the pumps, as well as during excessive floods. By the same experiments it was also proved, as stated in the report of Mr. Robert Stephenson and Sir William Cubitt, "that the delivery of the sewage at high water into the river, at any point, is equivalent to its discharge at low water at a point twelve miles lower down the river; therefore," it is added, "the construction of twelve miles of sewerage is saved by discharging the sewage at high instead or low water."

With regard to the second question, a mean velocity of one and a half miles per hour, in a properly protected main sewer, when running half full, was taken as sufficient,

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more especially when the contents have previously passed through a pumping station. This deduction is based on the experimental data supplied by Mr. Wicksteed at Leicester, Mr. Beardmore, Mr. John Phillips, in the first Report of Sanitary Commission, 1847, and Professor Robinson. In determining the quantity of sewage to be carried off, which is required as an element for calculating the fall of the sewers, Sir Joseph Bazalgette states that it varies but little from the water-supply with which a given population is provided, for that portion which is absorbed and evaporated is compensated for by the dry weather underground leakage into the sewers. The water supplied to London in 1856 varied from 20 gallons to 25 gallons per head of the population per day; but an improved supply at the rate of 5 cubic feet, or 31¼ gallons per head, was estimated upon. The population was taken as at the rate of thirty thousand per square mile, except over the outlying districts, where provision was made for only twenty thousand to the square mile. Sewage is not discharged at a uniform rate. Taking a liberal margin beyond the results of actual measurements made by Mr. Lovick, provision was made for one-half of the sewage to flow off within six hours of the day, and thus the maximum quantity of sewage likely to enter the sewers was estimated. The element of rainfall was also to be estimated. Sir Joseph Bazalgette ascertained that there are about a hundred and fifty-five days in the year upon which rain falls; of these there are about twenty-five days on which the rainfall amounts to ¼ inch in twenty-four hours, or at the average rate of $\frac{1}{100}$th part of an inch per hour. Of such rainfalls, a large proportion is evaporated or absorbed, and either does not pass through the sewers, or does not reach them until long after the rain has ceased. In the report of Messrs. Bidder, Hawkesley, and Bazalgette, in 1858, it is concluded, as a rule of averages, that ¼ inch of rain will not contribute more than ⅛ inch, or one-half, to the sewers, nor a fall of $\frac{4}{100}$ths of an inch more than ¼ inch, or five

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eighths. To allow for exceptional cases of heavy and violent rain-storms, which have measured 1 inch, and sometimes even 2 inches in an hour, overflow weirs, to act as safety-valves, were constructed at the junction of the intercepting sewers with the main valley sewers, over which the surplus waters, largely diluted, flow through the original channels into the Thames. The sewers have been made capable of carrying off a volume equal to a rainfall of ¼ inch per day during the six hours of maximum flow.

The pumping engines employed are condensing double-acting rotative beam engines, and the pumps are plunger or ram-pumps, the sewage being discharged from the pumps through a series of hanging valves. In accordance with one of the primary objects sought to be attained—the removal of as much of the sewage as practicable by gravitation, and the minimising of pumping work—three lines of intercepting sewers have been constructed on each side of the river, called respectively the High Level, the Middle Level, and the Low Level, according to the general plan shown in the Frontispiece. The High and Middle Level Sewers discharge by gravitation, and the Low Level Sewers discharge by the aid of pumping. The three lines of sewers north of the Thames converge and unite at Abbey Mills, east of London, where the contents of the Low Level are pumped into the upper level sewers. The aggregate stream flows thence through the northern outfall-sewer, which is carried, on a concrete embankment, across the marshes to Barking Creek, and discharges into the river by gravitation.

On the south side, the three intercepting lines unite at Deptford Creek, and the contents of the low level sewers are there pumped to the upper level, and the united streams of all three flow in one channel through Woolwich to Crossness Point in Erith marshes. Here the full volume can flow into the Thames at low water, but it is ordinarily raised by pumping into the reservoir, whence it is discharged at high water.

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The form generally adopted for the intercepting sewers —in which the flow is at all times considerable—is circular, which combines the greatest strength and capacity with the smallest quantity of brickwork and the least cost. In the minor branches for district drainage the egg-shaped section, having the narrow part downwards, was preferable, and was adopted, because the dry weather flow of the sewage being small, the greatest hydraulic mean depth, and consequently the greatest velocity of flow and scouring power, is obtained by that form in the bottom at the period when it is most required, and the broader section at the upper part provides room for the passage of the storm waters, as well as for workmen in repairing and cleansing.

The North Side of the Thames.

The High Level Sewer.—This sewer commences by a junction with the Fleet Sewer, at the foot of Hampstead Hill, and passes across the Highgate Road, through Tufnell Park Road, under the Great Northern Railway and the New River to Stoke Newington and Hackney, under the North London Railway, through Victoria Park, to a junction with the Middle Level Sewer. Down to this junction it is a draining sewer, and it is capable of carrying off the largest and most sudden fall of rain. It is about seven miles long, drains an area of about ten square miles, and intercepts the sewage of Hampstead, part of Kentish Town, Highgate, Hackney, Clapton, Stoke Newington, and Holloway. A portion of the district adjoining the Hackney Marshes is so low that it was necessary to drain it through a branch passing to the Low Level Sewer. The High Level Sewer is mostly circular in form. It varies in dimensions from 4 feet in diameter to 9½ feet by 12 feet. Its fall is rapid, ranging at the upper end from 1 in 71 to 1 in 376, or from 74 feet to 14 feet per mile, and at the lower end from 1 in 1,320 to 1 in 1,056, or from 4 feet to 5 feet per mile. It is constructed of

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stock brickwork, varying in thickness from 9 inches to 27 inches, and the invert is lined with Staffordshire blue brick, in order to withstand the scour arising from the rapid fall. One tunnel, from Maiden Lane towards Hampstead, is about half a mile long.

Under the Great Northern Railway, the sewer is 7½ feet in diameter, of 14-inch brick. Great care was necessary in tunnelling under the New River, its channel being on an embankment where it is intersected by the line of sewer, which is 8¼ feet in diameter, as shown in Fig. 84. Much house property at Hackney was successfully under-tunnelled. One house, adjoining the railway station, was under-pinned and placed upon iron girders, and the sewer, being there 9½ feet in diameter, was carried through the cellar without further injury to the house. The sewer is carried close under the bottom of Sir George Duckett's Canal, the soffit of the arch of the sewer being only 24 inches below the water of the canal. The bottom of the canal and the top of the sewer are here formed of iron girders and plates, with a thin coating of puddle, and no leakage from the canal has taken place. The whole of the High Level Sewer, including the penstock chamber, was completed and opened in May, 1861.

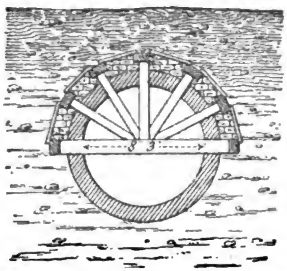

Fig. 84.—Sewer in tunnel under New River Embankment.

The penstock chamber, at the junction of the High and the Middle Level Sewers at Old Ford, Bow, is 150 feet in length, 40 feet in breadth, and 30 feet high. It is provided with five large penstocks or sluices worked by machinery, by which the sewage can be diverted at will, either into the two lower channels formed for the discharge of the storm-waters into the river Lee, or into the two upper channels constructed over that river, and forming

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the commencement of the Northern Outfall Sewer, Fig. 85. As a rule, the lower channels are closed, and the sewage

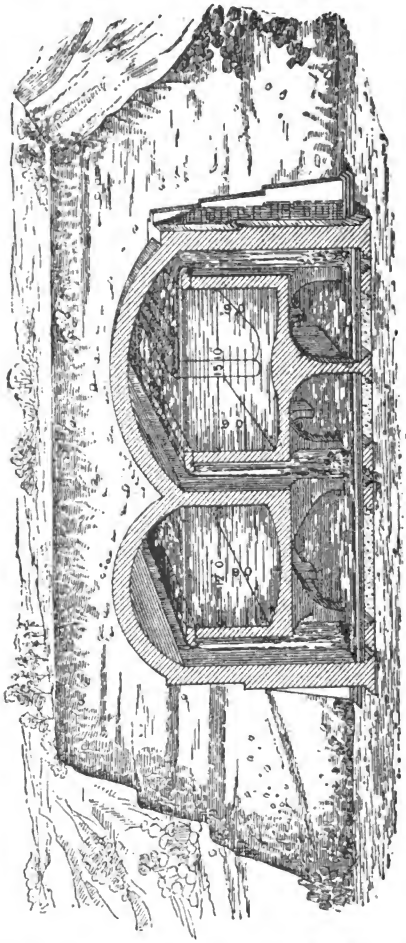

Fig 85.—Overflow Chamber at Junction of Northern High and Middle Level Sewers.

flows through the two upper channels to Barking Creek; but in times of heavy rain, as soon as the waters have risen to

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the top of the upper channels, the surplus flows over five weirs, constructed in the chamber, into the lower channels, and is discharged into the Lee.

The Middle Level Sewer was laid as near to the Thames as the contour of the ground permitted, with the object of intercepting as much sewage as possible by gravitation, and so reducing the low level area dependent upon pumping. The area intercepted by the sewer is 17¼ square miles in extent, and is densely inhabited. The sewer commences near Harrow Road at Kensal Green, passes into Uxbridge Road at Notting Hill, along Oxford Street,

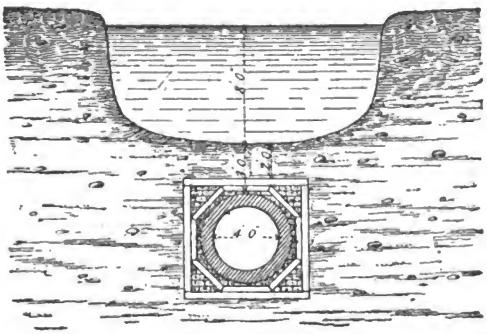

Fig 86.—Sewer in tunnel under Regent's Canal, Caledonian Road.

across Clerkenwell Green, by way of Old Street to Shoreditch, Bethnal Green Road, under the Regent's Canal, Fig. 86, and the North London Railway, to the junction with the High Level Sewer at the penstock chamber at Bow. To enlarge the area drained by gravitation, a branch sewer, 4 feet by 2 feet 8 inches in section, with a fall of 4 feet per mile, is carried along Piccadilly, through Liecester Square and Lincoln's Inn Fields, to the main line near Gray's Inn Road. The length of the main line is about 9½ miles, and that of the Piccadilly branch 2 miles. Besides these there are minor branches and feeders. The fall of the main sewer varies from 17½ feet per mile at the upper end,

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by a gradual reduction, to 2 feet per mile at the lower end. The sizes vary from 4½ feet by 3 feet, to 10½ feet in diameter, and, lastly, to 9½ feet by 12 feet at the outlet. About 4 miles of the main line and the whole of Piccadilly branch were constructed by tunnelling under the streets.

The Middle Level Sewer is carried over the Metropolitan Railway by a wrought-iron aqueduct of 150 feet span, weighing 240 tons. The sewer is provided with weirs, or storm-overflows, at its several junctions with the main valley lines. It was completed in 1864—65.

The Low Level Sewer intercepts the sewage from the low-level area of 11 square miles, and is also the main outlet for a district of about 14½ square miles, forming the western suburb of London. The sewage is lifted at Chelsea a height of 17½ feet to the upper end of the Low Level Sewer. This sewer begins in Pimlico, and passes to and along the river side from Vauxhall Bridge. From Westminster Bridge to Blackfriars it is formed as part of the Thames Embankment, whence it passes under Queen Victoria Street to Tower Hill, whence it passes to and along Commercial Road, and under the Limehouse Cut, Bow Common, and the river Lee, on its way to the Abbey Mills Pumping Station, where its contents are lifted 36 feet by steam power. The sewer has two branches, from Homerton and from the Isle of Dogs. The main line is 8¼ miles long, and its branches are about 4 miles in length. It varies from 6¾ feet to 10½ feet in diameter; with a fall of from 2 feet to 3 feet per mile. There are storm-overflows into the river.

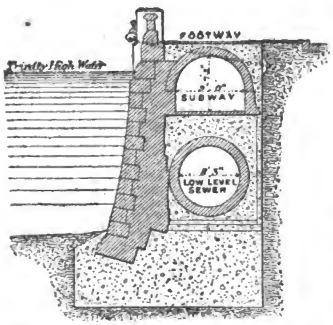

Fig. 86A.—Thames Embankment.

The western division comprises Fulham, Chelsea, Bromp-

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ton, Kensington, Shepherd's Bush, Hammersmith, and part of Acton. The main line varies in size from 4 feet by 2 feet 8 inches to 4½ in diameter, with a fall of 4 feet per mile, the depth below the surface being from 14 feet to 30 feet. The branch varies in size from 3¾ feet by 2½ feet to 4½ feet by 3 feet; the fall being 10⅛ feet per mile, and the depth below the surface about 17 feet. Besides these, there are various other minor branches and works. The works were executed mainly through gravel charged with such large volumes of water that it was necessary to lay stoneware pipes under the inverts of the sewers, to lower the water in the ground by means of numerous steam-pumps before the sewer could be constructed.

The Northern Outfall Sewer is a peculiar work. It is raised above the level of the surrounding neighbourhood in an embankment, like a railway embankment; and it is carried by aqueducts over rivers, railways, streets, and roads. It commences by a junction with the High Level and Middle Sewers, at the penstock-chamber at Bow, and passes immediately under the rails of the North London Railway, under Wick Lane, and over the river Lee by an aqueduct of 57 feet span, consisting of two wrought-iron culverts of the same section as the brick sewers. The sewers pass close under the rails of the Great Eastern Railway, up to which place the sewer consists of two culverts each 9 feet by 9 feet, side by side, with upright sides and semicircular crown and segmental inverts. These are built upon a solid concrete embankment, carried through the peat soil down to the gravel, in many places at a great depth. Concrete is also carried up with a slope of 1 to 1, so as to form an abutment to the sides of the sewers. The whole structure is then covered with an earthen embankment, with slopes of 1½ to 1, the foot of which is fenced by a simple quickset hedge and a ditch. From the Stratford Road, the double line of sewer is continued over Abbey Mill Lane by two wrought-iron tubes to the Abbey Mills Pumping Station, where the contents of the Low

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Level Sewer are raised 36 feet. From this point the parallel

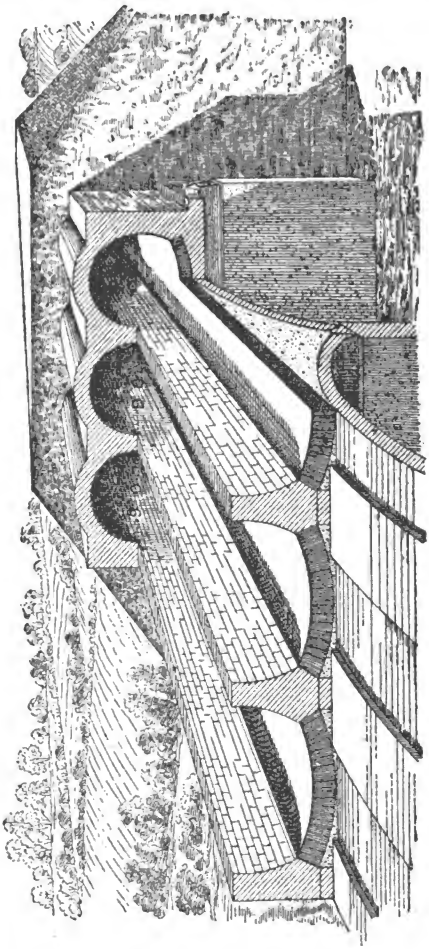

Fig. 87.—Northern Outfall Sewer. Section of Embankment, Culverts, and Substructure.

lines of sewer, Fig. 87, are continued to the outlet at Barking Creek. Gates and overflow weirs are formed in

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the line of the culverts, enabling the sewage to be turned into either or all of them at will, and preventing any one of them being at any time overcharged. For a distance of 1½ miles at the lower end of this sewer, through a deep bed of peat, cross trenches 6½ feet wide and 21 feet apart were excavated down to solid ground, and filled in with concrete piers, upon which brick arches of four rings in thickness were turned, the sewer being built on those arches. The top of the bank is 40 feet wide, and in some cases it is 25 feet above the level of the marshes. The triple sewer is constructed in brickwork, from the crossing of the Bow and Barking Railway to its outlet. The invert at the outlet is 18 inches below high-water mark; but, before entering the river, the sewage falls over an apron a depth of 16 feet, and is discharged by nine culverts, 6 feet by 6 feet, laid at the level of low-water spring tides. The reservoir is 16¾ feet deep, and is divided by partition walls into four compartments, covering an area of 412,384 square feet, or about 9½ acres. The walls are of brickwork, and the entire area is covered by brick arches, supported on brick piers founded on concrete. The sewers form one side of the reservoir, and a communication is made between them by sixteen openings, through which, when the penstocks are closed, the sewage enters the reservoir, where it is stored until high water. The sewage is ordinarily prevented rising above a certain level in the reservoir, by means of a weir or overflow in the partition-walls, which are built hollow, the spaces communicating with the discharging culverts below the outfall sewers. The Northern Outfall Sewer and reservoir were completed and opened in 1864. The sewer is 5¼ miles in length.

The Abbey Mills Pumping Station is the largest of the kind on the main-drainage works. It provides engine power to the extent of 1,140 horse-power, for the purpose of lifting a maximum quantity of sewage and rainfall of 15,000 cubic feet per minute a height of 36 feet. There are eight engines, worked in couples, with sixteen boilers.

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The cylinders are 4½ feet in diameter, with a stroke of 9 feet. The pumps are double-acting. Each engine works two pumps, 3 feet 10½ inches in diameter, with a stroke of 4½ feet. The boilers are doubled-flued, 8 feet in diameter, and 30 feet long. The engine-house is in three floors or compartments, the lower one being the pump-well into which the sewage is conveyed from the Low Level Sewer; the intermediate one forming a reservoir for condensing water, and the upper one holding the engines. The sewage from the Low Level Sewer passes through open iron cages, the bars of which intercept any substance likely to interfere with the proper action of the pump-valves; and it passes through into the wells, and is lifted by the pumps through hanging valves, into a circular culvert of cast-iron; and thence it is forced into any of the three culverts forming the Northern Outfall Sewer. This pumping station consumes about 10,000 tons of coal per year.

The South Side of the Thames.

The High Level Sewer and its southern branch correspond with the High Level and Middle Level Sewers on the north side of the Thames. The main line commences at Clapham, and the branch line at Dulwich; and they together drain an area of about 20 square miles, including Tooting, Streatham, Clapham, Brixton, Dulwich, Camberwell, Peckham, Norwood, Sydenham, and part of Greenwich. Both lines are constructed of capacity sufficient to carry off all the flood waters, so that they may be entirely intercepted from the low-lying district, which is tide-locked and subjected to floods. The storm-waters are discharged into Deptford Creek, whilst the sewage and a limited quantity of rain flow by four iron pipes, 3½ feet in diameter, laid under its bed, into the outfall sewer. The two lines meet in the New Cross Road, and are continued side by side to Deptford. At New Cross, the branch line is 10 feet above the main line, and falling more rapidly than the

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main line, it joins it on one level at Deptford Broadway. The branch is 4½ miles long: of which 1,000 feet were executed in tunnel at depths of from 30 feet to 50 feet. It varies from 7 feet in diameter to 10½ feet by 10½ feet, having segmental sides and invert, and a circular crown. Its fall varies from 30 feet per mile at the upper end, to 2½ feet per mile at the lower end. The old Effra Sewer, which fell into the river near Vauxhall Bridge, has been diverted to this sewer. Two subsidiary branches have been extended from the sewer at Dulwich: one to Crown Hill, Norwood, and the other to the Crystal Palace. The main line varies in size from 4½ feet by 3 feet at the upper end, to 10½ feet by 10½ feet, of the same form as the branch. The outlets of the two sewers, 10½ feet by 10½ feet, are each fitted with two hinged flaps, one above the other; the lower one being usually fixed close, so as to form a dam to drive the waters through the iron pipes into the Outfall Sewer; but the upper one hanging free, in order to serve as a tide flap, and allow of the exit of the sewage into the creek, when it rises in the sewer to a sufficient altitude. In cases of heavy floods, the lower flap can be opened to admit of a free and full discharge into the creek. The entrances to the iron pipes are in troughs or sumps in the large sewers, a short distance behind the outlet flaps, and are fitted with penstocks to shut off the sewage from the Outfall Sewer in case of need. The falls of the main line are, at the upper end, 53 feet, 26 feet, and 9 feet per inch to the Effra Sewer at the Brixton Road, and thence to the outlet 2½ feet per mile. The sewer is executed in brickwork, varying in thickness from 9 inches to 22½ inches, one half, that forming the invert being in Portland cement, and the remainder in blue lias mortar. The line was completed and opened in 1863.

The Low Level Sewer does not follow the course of the river, like that on the north side, but, commencing at Putney, it takes a more direct line through low ground which once formed the bed of a second channel of

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the Thames; and it drains an area of 20 square miles, comprising Putney, Battersea, Nine Elms, Lambeth, Newington, Southwark, Bermondsey, Rotherhithe, and Deptford. The surface is mostly below the level of high water, and is in many places 5 feet or 6 feet below it, having been at one time completely covered by the Thames. The sewers of the district have but little fall, and, except at the time of low water, they were tide-locked and stagnant. After long-continued rain they became overcharged, and were unable to empty themselves during the short period of low water. The waters were, therefore, constantly accumulating, and many days frequently elapsed after the cessation of the rain before the sewers could be entirely relieved, the sewage in the interim being forced into the basements and cellars of the houses. The want of flow also caused much accumulation of deposit in the sewers, the removal of which was difficult and costly. The Low Level Sewer has, in fact, rendered this district as dry and healthy as any portion of the metropolis. It is 10 miles long, and varies in size from a single sewer 4 feet in diameter at the upper end, to the culverts, each 7 feet high and 7 feet wide, at the lower end; and its fall ranges from 4 feet to 2 feet per mile. The lift at the outlet is 18 feet.

This sewer was constructed through a stratum of sand and gravel overlaying the clay, such as is frequently found in the beds of rivers, and copiously charged with water. Some very successful instances of tunnelling under canals, railways, and house property occurred in the construction of this work. A method of pumping in a quicksand, and rendering it dry and firm without drawing off the sand, was adopted. Cylinders were sunk at spots quite away from the line of the works, and to a depth considerably below that to which the works were to be extended. By this means the precise nature of the ground, and the quantity of pumping power that was required to overcome the water, were at once attained, and then, after thoroughly draining the ground, the works were commenced. A

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drain-pipe, and in some case two drain-pipes, were carried underneath the whole of the work and securely bedded in concrete; and this was found to be of the greatest value in getting in the foundations, which were thus done in a perfectly dry condition, Figs. 88, 89.

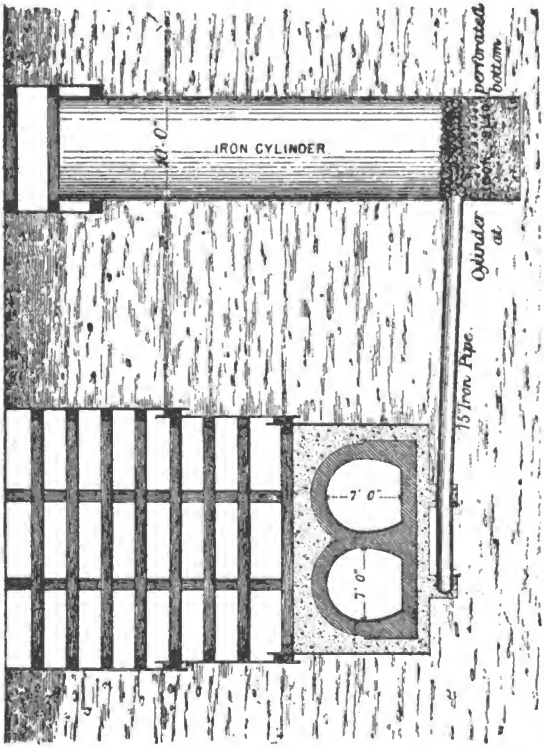

Fig. 88.—Low Level Sewer at Gas Works, Deptford. Section of Sewer and Sump.

Much difficulty was experienced in executing a portion of the work close to and below the foundation of the arches of the Greenwich Railway and under Deptford Creek, owing to the large volume of water there met with. Two iron cylinders, each 10 feet in diameter, were sunk

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through the sand to a depth of 45 feet, the water being kept down by pumping at the rate of from 5,000 gallons to 7,000 gallons per minute. The sewer was carried under Deptford Creek by constructing a cofferdam into the middle of the creek, executing one-half of the work at a time.

The sewers of this district had a fall generally from west to east, and had been connected with each other in such a manner that in case of one becoming first over-

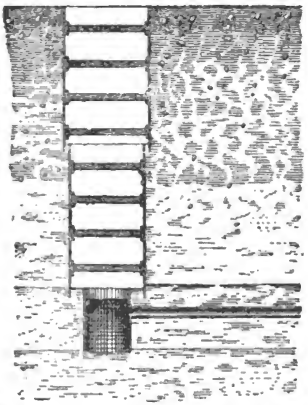

Fig. 89.—Sump, Old Kent Road.

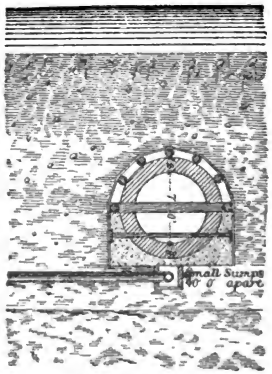

Fig. 90.—Sewer in tunnel under Grand Surrey Canal.

charged it might be relieved by its neighbour, and the sewage be reduced to a uniform level all over the district. Accordingly, a branch was constructed from the Low Level Sewer at High Street, Deptford, towards the river to St. James's Church, Bermondsey. This branch intersects the Earl, the Duffield, and the Battle Bridge Main Sewers, and relieves a large and populous district. It is 2 miles long; it is from 5 feet to 5½ feet in diameter, and it falls 4½ feet per mile. It is from 15 feet to 40 feet below the surface, and it has been in operation since 1864.

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The Deptford Pumping Station is by the side of Deptford Creek. The sewage is lifted from the Low Level Sewer a height of 18 feet into the outfall sewer. An iron wharf-wall and barge-bed, 500 feet long, has been constructed at the side of the Creek, and is provided with a crane and tramways for landing coal or other materials. Four rotative pumping engines of 152 horse-power each, are capable together of lifting 10,000 cubic feet of sewage per minute a height of 18 feet. They have ten Cornish boilers, each 30 feet long and 6 feet in diameter. The cylinders of the engines are 48 inches in diameter, with a stroke of 9 feet. The pumps, two of which are linked by one engine direct from the beam, are single-acting, plunger-pumps, 7 feet in diameter, with 4½ feet of stroke. The pump-valves are leather-faced hanging valves, and the sewage is discharged through them into a wrought-iron culvert placed on the level of the outfall sewer, and connected with it by a brick culvert, which receives also the sewage from the High Level Sewer, previously brought by gravitation under the Creek, through four cast-iron pipes 3½ feet in diameter. Both streams enter the outfall sewer, and they are together conveyed to Crossness, where they are again lifted. The chimney shaft at Crossness is 7½ feet in diameter at the base and 6 feet at the top, and is 150 feet high. The furnaces draw from the sewers and the engine-well to assist in the ventilation of the works. Provision is made by gratings for the interception of the larger substances brought down by the sewers. This station has been in operation since 1864.

The SOUTHERN OUTFALL SEWER conveys the sewage which flows into it from the High Level Sewer by gravitation through the four iron culverts laid under Deptford Creek, with that which is pumped into it from the Low Level Sewer, from Deptford through Greenwich and Woolwich to Crossness Point in the Erith Marshes. It is constructed for its whole length of 7¾ miles entirely underground. It is 11½ feet in diameter, in brickwork

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generally 18 inches thick; and it has a fall of 2 feet per mile. The bottom of the sewer is 9 feet below the level of low water at its outlet into the river, so that it can discharge into the river at and near to low water by gravitation in case of need; but ordinarily the discharge is by pumping into the Crossness reservoir. The sewer has been constructed at a depth of 16 feet below the surface, except where it passes through Woolwich, where it is from 45 feet to 75 feet underground. The large volume of water met with in the Plumstead Marshes rendered the construction of the lower part of the sewer very costly. It was completed and opened in 1862.

The outfall of the sewage on the south side of the Thames is at the Crossness Reservoir and Pumping Station. The sewage is discharged into the river at the time of high water only, but the sewer is at such a level that it can discharge its full volume by gravitation about the time of low water. Its outlet is ordinarily closed by a penstock placed across its mouth, and its contents are raised by pumping into the reservoir, which is built at the same level as that on the north side, and, like it, stores the sewage, except for the two hours of discharge after high water. The sewage is thus diverted from its direct course to the river into a side channel leading to the pump-well, which forms part of the foundation for the engine-house. From this well it is lifted by four beam rotatory engines, each of 125 horse-power, and actuating direct from the beam the compound pumps, each having four plungers. The cylinders are 4 feet in diameter, with a stroke of 9 feet. The pump-rods are connected to the beam at each side of the beam-centre. The steam is supplied by twelve Cornish boilers. The maximum ordinary quantity of sewage lifted is 10,000 cubic feet per minute. During the night it is less; but it is nearly doubled after a heavy rainfall. The lift varies from 10 feet to 30 feet, according to the levels in the sewer and reservoir. The pumps are single-acting, and have 4½-feet plungers. The plungers are placed in pairs,

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and may be partially thrown out of gear, according to the demand for power. The sewage is discharged into a wrought-iron trough through hanging leather-faced valves, which are suspended from wrought-iron shackles and fitted with wrought-iron back and front plates. Each valve is 18 inches by 12 inches. Substances likely to prevent the proper action of the valves are detained by a grating placed in front of the openings to the pump-well, the substances so intercepted being lifted from the face of the grating by an endless chain, with buckets or scrapers and combs attached, working vertically in front of and in close contact with the grating, the teeth of the comb passing between the bars. On the descent of the chain the buckets are overturned, and they discharge their contents into a trough, from which they are removed by manual labour.

The sewage is discharged through brick culverts into the reservoir, or, in case of need, provision is made for its discharge through other culverts directly into the river. After being stored in the reservoir till the time of high water, the sewage is discharged by a lower set of culverts into the river. There are two tiers of eight openings in each compartment of the reservoir, the upper eight for the admission of the sewage from the pumps to the reservoir, and the lower eight for its discharge into the river, the apertures in all cases being opened and closed by penstocks. The reservoir is 6½ acres in extent, and is covered by brick arches supported on brick piers, and is furnished with weirs for overflows and with a flushing culvert. In height, level, and general construction it is similar to that at Barking Creek, already described. Over the reservoir are built twenty-one cottages for the engineers and other persons employed upon the works. The ground on which these works were constructed consists of peat, sand, and soft clay, and affords no sufficient foundation within 25 feet of the surface. To minimise expense for foundations the culverts on the various levels were built, as far as was

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practicable, in the same trenches, one above another. The boilers and stokehole floors are supported on arches which spring from walls brought up from the gravel. A wharf wall of bricks on brick arches, resting on piers built up from the gravel, has been constructed along the river frontage of the works for a distance of 1,200 feet. The piers are formed of iron caissons filled with concrete. The chimney is 200 feet high and is 8¼ feet in diameter internally. The reservoir, as well as the culverts and pump-wells, are all connected by flues with the furnaces of the boilers, for purposes of ventilation, in a manner similar to that adopted at the Deptford and other pumping stations.

The outlet from the outfall sewer into the river, consists of twelve iron pipes, 4 feet 4 inches in diameter, carried under the "saltings" into a paved channel formed in the bed of the river. These pipes are gathered into the single sewer, by culverts in brickwork on the land side of the wharf wall, the culverts being gradually reduced in number, and their dimensions increased, as they approach the junction with the large outfall sewer. These works were completed early in 1865.

The tunnelling and the formation of the sewers through quicksands charged with large volumes of water were rendered practicable and safe by a method of pumping water out of the ground, without withdrawing the sand. The method adopted was first to sink in some convenient position near the intended works, a brick well to a depth of 5 feet or 6 feet below the lowest part of the excavation. In some cases, for great depths, an iron cylinder was sunk below the brickwork, and the bottom and sides of the well were lined both with shingle, which filtered the water passing into it, and exposed a large surface of this filtering medium. Earthenware pipes were carried from this well and laid below the invert of the intended sewer, small pits being formed at the mouths of these pipes, to protect them from the deposit. By these means, the water has been successfully withdrawn from the worst quicksands, and

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they have been rendered firm and dry for buildings on them. But, unless the ground is so dry and solid that it can be excavated to the exact form of the sewer to be placed on it, there is no portion of the work more important than the effectual backing of the invert and the haunches with concrete.

The bricks used in the works have been mostly picked stocks, and gault clay bricks, and the inverts were occasionally faced with Staffordshire blue bricks. The brickwork is laid in blue lias lime mortar, mixed in the proportions of two of sand to one of lime, for one half or two-thirds of the upper circumference of the sewers, and the remainder has been laid in Portland cement mixed with an equal weight of sand. A very considerable length of sewer has been laid entirely in cement. The specifications provide that the whole of the cement shall be Portland cement of the very best quality, ground extremely fine, weighing not less than 110 pounds to the bushel, and capable of maintaining a breaking weight of 500 pounds on 1½ square inches, seven days after being made in an iron mould, and immersed in water during the interval of seven days.

The total cost of the main drainage works amounted to about £4,100,000. There were, in 1865, a total of about 1,300 miles of sewers in London, and 82 miles of intercepting sewers; 318,000,000 bricks and 880,000 cubic yards of concrete have been consumed, and 3,500,000 cubic yards of earth have been excavated in the execution of these works. The total pumping power employed was 2,380 nominal horse-power. The average actual consumption of coal is estimated at 20,000 tons per year. If at full work day and night, 44,000 tons of coal would be consumed per year.

The lengths of the main intercepting sewers herein noticed, with the areas served, dimensions, and the falls of the sewers, are abstracted in the following table:—

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TABLE XXI.—The Main Drainage of London.

Section of Sewers.	Length of Sewers.	Area served.	Dimension of Sewers.	Fall per Mile.
	Miles.	Square miles.		
North Side of the Thames.				
High Level	7	10	4 ft. diam. to 9½ ft. × 12 ft. diam.	14 ft. to 74 ft. at top, 4 ft. to 3 ft. at bottom
Middle Level	9½	17½	4½ ft. × 3 ft. to 10½ ft. diam., and 9½ ft. × 12 ft. at outlet.	17 ft. at top to 2 ft. at bottom.
Do. Piccadilly Branch	2	—	4 ft. × 2 ft. 8 ins.	4 ft.
Low Level	8¼	11	6¾ ft. to 10¼ ft. diam.	2 ft. to 3 ft.
Do. Branches	4	—	—	—
Western Division ..	5¾	14½	4 ft. × 2 ft. 8 in.	4 ft.
Outfall	5¼	—	2 and 3 culverts, 9 ft. × 9 ft.	2 ft.
South Side of the Thames.				
High Level	9½	20	4½ ft. × 3 ft. to 10½ ft. × 10½ ft.	53 ft., 26 ft., and 9 ft. at top to 2½ ft. bottom.
Do. Branch	4½		7 ft. diam. to 10 ft. × 10 ft.	30 ft. at top to 2⅓ ft. at bottom.
Low Level.....	10	20	4 ft. diam. to 7 ft. × 7 ft.	4 ft. at top to 2 ft. at bottom.
Do. Branch	2	—	5 ft. to 5½ ft. diam.	4½ ft.
Outfall	7¾	—	11½ ft. diam.	2 ft.

Total length of all Intercepting Sewers, 82 miles.

III.—The Main Drainage of Torquay.

Torquay, on the northern shore of Torbay, is a town of upwards of 30,000 inhabitants. In 1867, it was observed that "night-soil fever prevailed where the sewerage was defective." At that period, nearly the whole of Torquay

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was supplied with sewers, by which the old cesspools were supplanted. But the main sewers were constantly closed at their outlets by the sea, which at high water flowed up a considerable way into the town; many of them were of insufficient capacity, and, the ventilation being defective, foul gases were driven into the houses. During heavy rain, the basements were flooded, and the discharge of sewage into the bay had become very offensive in hot weather at low water.

Torquay, with it suburbs, is divided into three distinct drainage areas, the sewage of which was formerly discharged into the bay by three different outfall sewers. 1. The Tor Abbey district. The upper part drained into an open channel, the lower and urban part into a brick sewer 18 inches in diameter at the upper end, and enlarged below to an egg-shaped section $3\frac{3}{4}$ feet by $2\frac{1}{2}$ feet. The outlet, known as Corbyn's Head, was closed at its entrance into the sea, and thence it discharged into deep water through a 15-inch pipe, 600 feet long. 2. The Upton Valley district, which contains the greater part of the population. The upper portion is suburban, and the floodwaters are carried off by an open channel down to St. Mary Magdalen Church. Here the Channel is joined to a barrel drain, 2 feet in diameter, carrying the sewage of Upton; and also by the branch sewers from Boston Fields and Torhill Road. Thence, a sewer of varying size and inclination passes down generally in the line of Fleet Street and Union Street. It originally had an outfall into the Bay, at the level of half tide, at a point in the New Road west of the harbour, where it was 5 feet deep and 3 feet 4 inches wide, fitted with flaps, and whence it was continued into the bay by an 18-inch pipe 300 yards long. This pipe was not of much use except about the time of low water. When the tide had risen to the level of the invert of the main sewer, the sewage was discharged close to the New Road, a frequented promenade, instead of through the iron pipe. In wet weather this occurred at nearly all times of the tide.

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3. The sewage of the Meadfoot district was discharged at the Meadfoot beach through a 15-inch pipe, having the outlet at low-water line.

The quantity of water brought into the town daily by the waterworks is about 1,000,000 gallons. The dry-weather flow of the sewage is about 1,250,000 gallons, the excess being caused by the streams, springs, and overflow of wells, which have been taken into the sewers.

A combined high-level and low-level system of drainage, designed by Sir Joseph Bazalgette, was adopted in 1872, with an outfall into the sea at Hope's Nose, and this design has now been executed. The high-level sewer commences near the Abbey at the lower end of Mill Lane, the invert at this point being 34 feet above Ordnance datum, the level of high-water spring tides being + 8·16 feet.

The total length of the high-level sewer is 17,030 feet, made up of sewers of the sizes and gradients following :—

High Level Sewer, Torquay.

Size.	Length.	Gradient.
	Feet.	
2½ ft. by 1 ft. 8 ins., egg-shaped	1,206	1 in 120
" " "	367	1 in 59
2½ ft. in diameter	1,720	1 in 1000
4 " "	1,000	1 in 1000
5½ ft. by 4 ft., oval.....	1,200	1 in 1000
Two lines of cast-iron pipes 3 ft. in diameter	150	1 in 1177
Barrel sewer 7 ft. in diameter	11,387	1 in 1177

The high level sewer traverses Torquay in almost a direct line, as shown on the map, Fig. 91, from west to east; and it extends from end to end of the entire district. Of the total length, more than half—10,172 feet—has been constructed in tunnel, for the most part in rock. There are three tunnels. The sewer at the lower end of Mill Lane, Fig. 92, is egg-shaped, 2½ feet by 1 foot 8 inches. The invert is of Portland-cement concrete, and the arch is

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of brickwork in cement. It passes along the road to Tor Abbey, where it is circular, 2½ feet in diameter, of 4½-inch brickwork, founded in and surrounded by lias lime concrete,

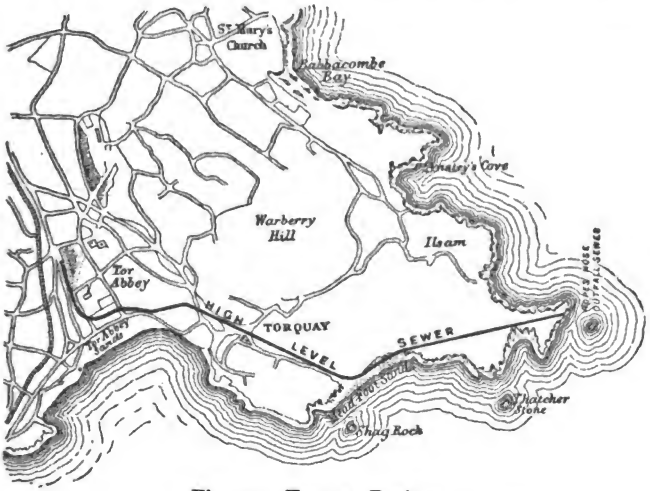

Fig. 91.—Torquay Drainage.

Fig. 93. Where the sewer runs parallel to and near to the stream, the concrete foundations were carried through

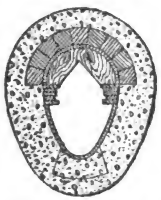

Fig. 92.—Sewer, 2½ feet by 1 foot 8 inches.

Fig. 93.—2½ feet Sewer.

the peat to a solid bottom at a considerable depth, and the side next the stream was protected by a limestone rubble retaining wall, the same being under the footpath of the

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new road, with which it was formed in conjunction, from the end of Long Avenue. The 2½-feet sewer extends as far as Belgrave Road, and is in some places out of the ground. Thence to where it runs into Waldon Hill it is circular, 4 feet in diameter, partly in tunnel through sandstone easily excavated, and lined with 9 inches of brickwork. From behind Abbey Crescent to Waldon Hill the sewer was executed entirely in Portland-cement concrete, and rendered internally with cement. The 5½-feet by 4-feet sewer extends from about 300 feet east from Abbey Crescent in a direct line through Waldon Hill to the Rock Road steps in Swan Street. The tunnel is 1,150 feet long, and the maximum depth below the surface is 212 feet. The pumping-station is at the Rock Road steps. Two lines of 3-feet cast-iron pipes connect the 5½-feet by 4-feet sewer with a 7-feet barrel sewer, which is continued to the outfall.

From Fleet Street the main sewer passes to the Meadfoot Beach. It is a tunnel for a length of 4,456 feet, at a maximum depth of 171 feet, through limestone principally, and also through shale, stiff clay, and treacherous heavy ground. A new roadway, and a sea-wall 1,900 feet long, were constructed along the Meadfoot Beach. The sewer, Fig. 94, runs under the road, and it consists of a single ring of brickwork, surrounded with and founded upon lias lime concrete, carried down to the solid rock. The wall is of random-coursed limestone masonry, backed with rubble; all the joints of the outer face, up to a level of 3 feet above high water of spring tides, are of Portland cement, and the rest are of lias-lime mortar. The parapet is almost entirely of headers, which at short intervals are built into the wall to a depth of more than 3 feet.

From Meadfoot Beach, the sewer passes into Kilmorie Hill, and is in tunnel to Hope's Nose, a length of 4,564 feet. The nature of the rock varied greatly—argillaceous and silicious grit, shale, and limestone. Nearly the whole length of the tunnel was lined with either brick or Portland-cement concrete. The high-level sewer is ventilated

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by openings at thirteen places: No. 2 shaft is at Kilmorie; two shafts are on Meadfoot Beach; No. 11 shaft at pumping station, off Torbay Road. There is a chamber fitted with a hanging flap just above the Kilmorie ventilator, so that air cannot be driven during the time of high water by a heavy sea into the town. There are also several manholes not used as ventilators. The flow of sewage is continuous —a condition favourable for the prevention of sewer gas.

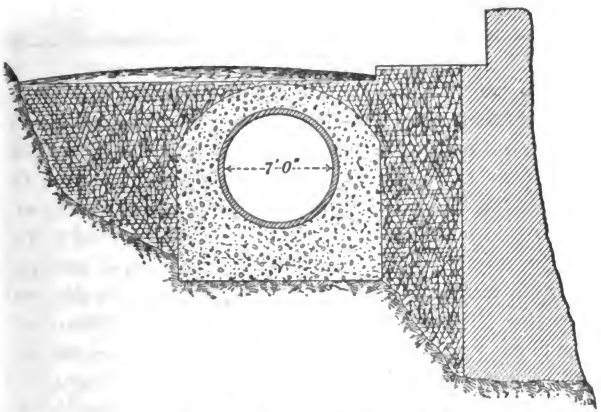

Fig. 94.—Sea-wall, Sewer, and Road, at Meadfoot Beach.

Large catch-pits for intercepting the road detritus have been made at Long Avenue, Belgrave Road, Fleet Street, Babbacombe Point, and Meadfoot Road. They require to be cleared out frequently in wet weather; but there has not been any deposit in the high-level sewer.

Low Level Sewers.

The low-level system receives the sewage of about one-tenth of the population of Torquay. It is 5,184 feet in total length, composed as follows:—

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Size.	Length.	Gradient.	Locality.
	feet.		
12-inch pipe	1,200	{ 1 in 45 / 1 in 300 }	Beacon Terrace.
„	300	1 in 100	Market Street.
„	317	1 in 130	Vaughan Parade.
„	2,207	1 in 350	Torbay Road.
15-inch pipe	660	1 in 500	Strand.
3 feet barrel sewer	500	1 in 500	Swan Street.
Total length....	5,184		

The pipes are jointed in cement, surrounded with concrete, and made as watertight as possible. The rainfall is admitted into the old sewers. The invert of the 3-feet barrel sewer at the pumping station is 3·6 feet above Ordnance datum, and that of the high level sewer at the same point is + 13·8 feet, making a lift of (13·8 — 3·6 =) 10·2 feet from invert to invert. The low-level sewage is lifted by a water-pressure engine, with pumps in duplicate, capable of lifting 14,000 gallons per hour. The pumps are worked by a head of 250 feet of water from the town main, and they are arranged with automatic regulators. The actual quantity of water used for this service, in 1879, was 6,593,000 gallons, which, at 4d. per 1,000 gallons, cost about £110 per year.

At an early period in the construction of the works, a storm-overflow was made to relieve the existing Fleet Street sewer until the high-level sewer was completed. It is 4 feet in diameter and 850 feet long, constructed entirely in Portland-cement concrete. The invert level at the outfall at the sea-wall, Cary Green, is 4·9 feet above Ordnance datum, and 12·8 feet at the point where it joins the old sewer. Almost immediately on its completion the utility of this overflow was clearly demonstrated, for, after a heavy, rainfall, the landwater and sewage coming down Fleet Street, being intercepted at a high level, were carried

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direct into the bay instead of into the basements of the low-lying property, where formerly, after even a moderate rainfall, it had damaged property to an amount in excess of the total cost of the new overflow. This overflow is now connected with the high-level sewer.

The Waldon Hill tunnel, 1,150 feet long, was driven through limestone rock, and when entirely driven, it was lined with Portland cement concrete, averaging 6 inches in thickness.

The Meadfoot Hill tunnel is 4,458 feet in length. When the ground was soft it was taken in 12-feet lengths and timbered, the bricklayers following the miners into the heading. The general thickness of the brickwork is 9 inches; it was set in blue lias lime mortar.

The Kilmorie tunnel, leading to the outfall at Hope's Nose, was driven through very hard rock, which, having baffled the efforts of the hand-miners, was excavated by means of Ingersoll's rock-drills, driven by compressed air.

The discharging capacity of the high-level sewer, when full, is 8,380 cubic feet per minute. After continuous rain, the discharge has been 4,380 feet per minute, or about thirty-three times the rate of the average dry-weather flow.

The sewage escapes at the outfall by an excavated channel into the sea, whence it goes out in nearly a straight line in the direction of the sewer through the hill, and is seldom deflected to one side or the other. In calm weather and in particular states of the atmosphere, there is no difficulty in tracing the sewage for a considerable distance; and it has been repeatedly observed that it does not under any circumstances return into the bay.

The total cost of the main drainage works to the Local Board amounted to £66,145. They were constructed in part by contractors, but much the greater part was executed by the Local Board by administration.

The average cost of the Waldon Hill tunnel was as follows:—

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	Per lineal foot.
Driving 675 feet	£1 11 0¾
Trimming	0 2 3¼
Driving and trimming . . .	1 13 4
Lining the tunnel	0 2 8
Total cost of completed sewer .	1 16 0

The cost for driving and trimming, £1 13s. 4d. per lineal foot, is equivalent to £1 19s. 2d. per cubic yard of work excavated.

The Meadfoot tunnel, 4,183 feet long, cost £10,382 19s. 10½d., or £2 9s. 7¾d. per lineal foot. For driving only the cost was £1 9s. 1¼d. per lineal foot.

The Kilmorie tunnel, 4,564 feet in length, cost as follows:—

			Per lineal foot.
Driving . . .	£10,701 9 6	or	£2 6 10¾
Trimming . .	2,294 5 8	„	0 10 0½
Driving and trimming	12,995 15 2	„	2 16 11¼
Lining . . .	1,363 3 3¾	„	0 5 11¾
Total cost of sewer	14,358 18 5¾	„	3 2 11

IV.—The Main Drainage of Brighton.

Until about forty years ago the sewage and household water of Brighton were drained into cesspools. Rain-water was discharged through sewers into the sea. When the houses were drained into the sewers these became a nuisance. There was a trunk in the centre of the town, opposite the central valley, to carry the sewage to low-water mark; but, being a structure 10 feet high, made of wood, and subject to the action of the waves, it leaked very much, and the sewage was really delivered immediately on the shore, and was very offensive. Mr. P. C. Lockwood, Borough Surveyor, laid a 12-inch iron pipe to carry the sewage out to low-water mark, which proved successful, and induced the corporation to lay a 3-feet pipe, 1,760 feet long and another 2,000 feet long at the western district, extending 1,500 feet

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beyond low-water mark. The lowest depth of water at these points was from 8 feet to 16 feet above the ends of the pipes, and the sewage was continuously delivered at the rate of from 2 to 3 miles per hour, and, according to Mr. Lockwood, it was disposed of before it could reach the shore. With a south-west wind, he says, it might at times have reached the shore; but before it could do so it was so oxidised by the air and the water as to be practically harmless. But at the western boundary of Brighton, where it joins Hove, there was an outfall which only reached to low-water mark, and which was a serious cause of offence. From the three pipes, 10,000 cubic feet of sewage was discharged per minute, with a velocity of 580 feet per minute. The flattest gradient in the old sewers was 1 in 218, or 24 feet per mile, and the whole of the sewage in its entirety was taken into the sea. The pipes were put together with lead joints, and floated out in lengths of from 550 feet to 300 feet, the joints at the ends of each section being made with wooden wedges, and the whole secured by screw-piles. They were perfectly tight. A short time before the project for an intercepting sewer was entertained, Mr. Lockwood examined the mouth of the principal outfall pipe, and he found that the bed at the bottom of the sea was perfectly clean. The outfall scoured for itself a clean place, and there was no sand around it—nothing but white chalk, which could be seen from a boat when the water was clear. The three outfalls still serve to receive the storm overflow from the new sewers.

The new intercepting sewer conveys the sewage from west to east, to the new outfall at Portobello, according to the design of Sir John Hawkshaw. The intercepting sewer begins at Hove Street, passes under the Shoreham Road, and under the beach as far as East Street. For nearly all the remaining distance the sewer passes under the Marine Parade and Newhaven Road to Portobello. The length and size of the sewer are as follows:—

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	feet.
Circular sewer, brickwork, 5 feet in diameter up to East Street	9,900
Do. 6 feet in diameter to the Steyne . . .	710
Do. 7 feet in diameter to the penstock chamber, Portobello	27,460
Between the penstock chamber and the sea, partly of brickwork, partly of three cast-iron pipes, 4 feet in diameter, side by side	520
Total distance ($7\frac{1}{4}$ miles) . . .	38,590

The fall is 3 feet per mile, excepting the last mile before the penstocks, where it is only 1 foot. It is 2 feet between the penstock-chamber and the outfall; and as there is a steeper gradient for a short distance near Hove Street, the average fall is about 3 feet per mile. The invert at Hove Street is $21\frac{1}{2}$ feet above low-water of spring tides; at the penstock chamber it is 2 feet above it, and at the outfall it is on the same level. The discharge of a circular sewer, 7 feet in diameter, with a fall of 3 feet per mile, when full, is, by Eytelwein's formula, 7,280 cubic feet per minute.

A catch-tank is placed on each tributary sewer just above its junction with the intercepting sewer, in which road-grit, stone, and other heavy materials are trapped, which would otherwise get into the main sewer. All the tanks are ventilated by shafts up to the roads. The tank at the Steyne, Fig. 95, is 40 feet long, 18 feet wide, and is deeper than the sewer. In the junction or tumbling bay built at Rottingdean for connecting the village sewer, the invert of the main sewer is 50 feet below the surface of the road, and communication is effected by means of a vertical shaft, in which the descent is broken off into six falls of 6 feet each. Flagstones are for this purpose built into the walls of the shaft, projecting alternately from opposite sides more than half-way across the shaft. Each flag is set to a slope of 3 inches, in order to prevent lodgment of water or solid matter. Ladders are provided in the shaft so that the flushers may clean down

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the shaft. A small catch-pit, 12 feet long, is built at the top of the shaft.

There are sixty-one ventilators on the line of the main sewer, at distances of about 200 yards apart. Of these, twenty-four are supplied by side entrances, including the penstock chamber. Nine ventilators are fitted with hand-and-foot irons built into them, making thirty-three available entrances between Hove Street and the penstock chamber.

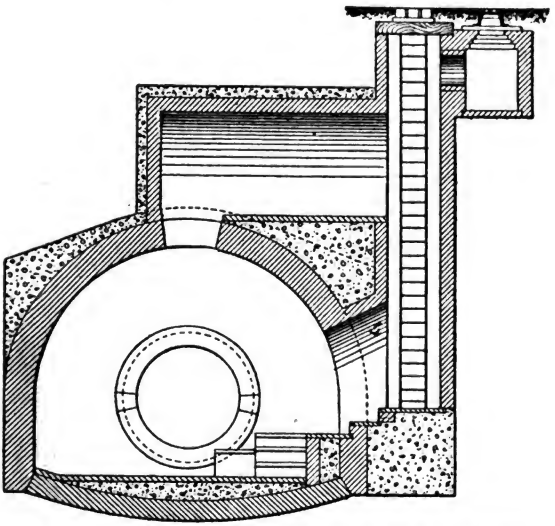

Fig. 95.—Catch-tank, Main Valley Junction, at Steyne.

Four of them have entrances from the beach, as well as winding staircases to the road. The gratings are not directly over the sewers; they are at one side, over a small catch-pit for stones and dirt. The grates are cast-iron, in two parts, of which the outer part is bedded in the road-way as a frame, to receive the grit, which is lodged in it, and which may be lifted, when required, to give access to the catch-pits.

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There are three storm overflows in Brighton: the western, 4 feet above high-water of spring tides; the central, 3 feet above it; and the eastern, 2½ feet above it. During the first six months after the sewage was let in, the central overflow in the main valley had come into operation three times, and the two others had operated once, on which occasion the fall of rain was nearly 1½ inch in twenty-four hours. In the second six months, the storm overflow came into operation only once. In the overflow at Steyne, Fig. 96, a weir is built in a slanting direction across the old sewer, and the ordinary drainage passes along a new sewer towards its junction with the intercepting sewer. The level of the top of the weir is 2 inches higher than the old storm overflow farther down the old sewer, so that practically the same relief is afforded as before.

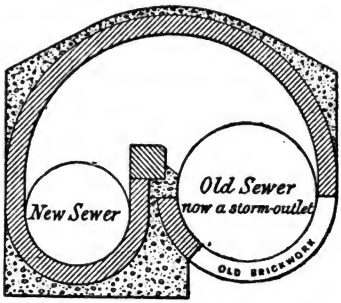

Fig. 96.—Storm Overflow at the Steyne.

One inlet has been constructed at the Steyne, with penstocks to admit sea-water to flush the sewers, generally at spring tides. The upper end of the sewer is above high water, and flushing water is obtained by pumping, or from the waterworks.

The penstock chamber, 45 feet by 16¾ feet, contains the self-acting valves, and two sets of penstocks, of which one set is employed to shut out the tide in case of the valves not acting. The other is employed for penning back the sewage temporarily, so as to flush the outfall at low water. Between the penstock and the sea, the section of the sewer changes from a circle to a semicircular arch with a flat invert, Fig. 97, and from that to three iron pipes in a

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vertical row. Beyond the ends of the pipes the sewage runs in a trench in the beach, only visible at low water of spring tides.

The works were commenced in January, 1871, and completed in June, 1874. The brickwork was shown to be 9 inches thick on the contract drawings; but between Rottingdean and the penstock chamber the thickness was increased to 13½ inches, and thence to the sea to 18 inches. The brickwork of the sewer was set in Portland cement mortar (2 of sand to 1 of cement); the walls of the penstock chamber were set in greystone lime mortar. Gault pressed bricks were used in the inverts, and ordinary gault or stock bricks in the arches. To keep the works clear of water, thirteen 20-inch pumps were employed, driven by one 50 horse-power stationary engine, and eight portable engines averaging 14 horse-power each. The ventilation of the sewer, in progress, was good in every portion where there were two openings. Where there was only one opening, the air in the heading became bad at 500 or 600 feet from the shaft, and openings to the cliff were frequently made.

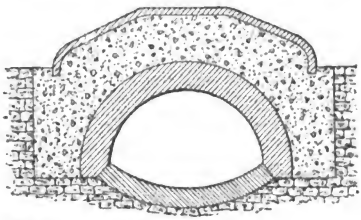

Fig. 97.—Sewer on Beach at Outfall.

The total cost of the work to the Board was about £100,000, but the actual cost was £40,000 more. The cost of a lineal foot of the 5-feet sewer, which was built almost entirely under the first contract, and in open cuttings, was 29s. The cost per lineal foot of the 7-feet sewer, 9-inch work, done by tunnelling, was 27s. under the first contract, 41s. under the second contract. The cost of a ventilator varied from £20 when the sewer, as at Clifton Villa, was not far from the surface, to £160 when the ground-level was from 150 feet to 160 feet above the in-

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vert. The ventilators, including catch-pits, gratings, &c., may be said roughly to have cost £1 per vertical foot.

By letting water in at the Steyne, at spring tides, and by occasionally keeping the penstocks shut till low water, the sewer is cleansed of all deposit between the Steyne and Portobello. The sea-water is admitted at spring tides for four or five days in succession. In addition, the upper end of the sewer is flushed twice a week, or oftener in dry weather, by penning back the sewage by a sluice.

That it is not necessary to raise any deposit out of the sewers between the Steyne and Portobello is a result due chiefly to the greater part of the deposit having been intercepted in the catch-tank at the Steyne, which is cleared out nearly every night. The other catch-tanks do not require to be cleansed so frequently; but their utility, and the consequent saving of labour and maintenance have been clearly shown.

Notwithstanding, it is necessary to employ six flushers, men whose duty it is to clear out the deposits of silt by flushing. The range of the tide is 22 feet; the invert at Hove is 21·6 feet above low water, and the point of outfall is exactly at low water. The sewage is for the most part of the day blocked in by tide, and there being no current at all, sludge is freely deposited. From six loads to twenty-one loads of silt are lifted from the catch-pits per week; the total quantity in seventy-five weeks (from July, 1874, to December, 1875) having been 740 loads, or about ten loads, on the average, per week. A load is a little more than one cubic yard in volume.

In view of the great quantity of sludge deposited in the sewer, putrefaction must be active, and, in fact, large volumes of sewer gas are given off, escaping through the ventilators, which are in the high road of the principal drive, and some of them in the centre of the town. In frosty weather watery vapour can be seen issuing from the middle of the street. Multiplying the length of the sewer by the diameter, the evaporating surface covered with

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sewage, or deposit from sewage, amounted to about 253,000 square feet. Since the work was completed, a ventilating chimney, 100 feet high, has been erected, one mile eastward of Kemp Town, having an area of 10 square feet at the summit, with a fire-grate area of 20 square feet. This chimney is in close proximity to a shaft, 100 feet deep from the road to the sewer, making together a draught-height of 200 feet, by which a powerful ventilation is established. A tidal valve is introduced in the sewer at the same point, which opens for the sewage, and shuts out any air or other gases coming from Portobello.

The discharging power at the outfall is about 8,0c cubic feet per minute. According to another estimate, the quantity of sewage is at the rate of under 25 gallons, or 6 cubic feet per head of the population, in twenty-four hours. In the daytime, when there is no rain, the ordinary depth of sewage is 12 inches, and the maximum velocity is 84 feet per minute, or nearly one mile per hour. At night the flow is about 6 inches deep at the Chain Pier, and 10 inches at Portobello.

It is questionable whether the new intercepting sewer answers the purpose of the main drainage of Brighton any better than the direct system which preceded it. In the latter, the gradients were much steeper than in the former, and were such that the whole of the sewage was carried directly into deep water, without leaving deposits. So thoroughly did they act that during the whole of the ten years in which they were at work, they did not require any attention whatever.

A greater degree of continuity of flow would have been obtained if the fall of the intercepting sewer had been less, say 2 feet, as suggested by Mr. Grant, instead of 3 feet per mile, and so placing the outfall at a level 7 feet higher than where it is. The outfall could then have been kept clear four hours out of the twelve. To compensate for the lower rate of flow, the sewer could have been made a little larger.

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V.—Drainage Works of Newport, Monmouthshire.

The borough of Newport, in 1863, covered an area of 950 acres, with a population of 23,248 persons. It is situated on the River Usk, which is discharged into the Bristol Channel about 3¼ miles below the borough. The river, at the upper part of the town, is 450 feet wide at high-water spring tides, and has a sectional area of 12,000 square feet. At the lower part of the town, it is 900 feet wide, with a sectional area of 26,500 square feet. The rise of the tide in the river at ordinary springs is 35 feet, and at extraordinary springs, about 40 feet. It occupies only five hours, the current being necessarily very rapid.

Before the construction of the new system of sewers, several miles of sewers and drains had at different times, during a long series of years, been constructed on the western side or right bank of the river, where nearly all the town stands. These were for the most part of rude design and rough material. Many of them were small and square, and others were merely a rough stone arch over a ditch, without an invert. In many cases they were built to preserve the old watercourses and field-ditches, without regard to the intended street-lines or buildings, and they often passed obliquely under houses and gardens. In the greater proportion of the town, cesspools were used. These old sewers, varying from 1 foot to 4½ feet in height, had nine open outlets into the river varying in level from 5·4 feet to 12·9 feet below high-water of ordinary spring tides. The tide flowed up the sewers and frequently flooded the cellars and basements.

According to the design of the new system of sewers, designed by Mr. Alfred Williams, it was arranged that the number of outlets was to be reduced from nine to four by means of intercepting sewers; that the sewage of two-thirds of the town should be brought to the lowest outlet down the river, near the extremity of the borough; and that by a

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further expenditure, if justifiable, the greater portion of the remaining third might be brought to the same outlet; that the gradients were to be generally favourable, the lowest inclination of any new sewer being 1 in 488, or about 11 feet per mile near the lowest outlet, and nearly half the entire length of new sewers being steeper than 1 in 100; and that no cost was to be incurred for flushing.

The system comprised about 7 miles of new brick sewers varying in height from 14 inches to 4½ feet; all above 14 inches being egg-shaped and narrow at the invert, with outlet works; a sufficient number of entrances with ventilating shafts, and street gullies. The provision of several outfalls into the river within the borough was considered to be permissible, in the exceptional case of Newport, where the size of the river and the extraordinary rise of tide render the volume of sewage matter discharged into the river comparatively insignificant.

Of the four outfalls, two are old outlets where a large quantity of land-water is discharged. For the other two, places were selected which would be suitable for the utilisation of the sewage, if that should be found profitable, where the sewage water would have a short and steep run into the stream at low-water, and where only short lengths of pipes would be required, should they be found necessary. The level of the cills of the old outlets are 8·8 feet and 12·6 feet below high-water of ordinary spring tides, and those of the new outlets are 9·8 feet and 12·6 feet. The outlets are closed by valves when they are covered by the tide, and they for a time act as reservoirs. The valve consists of an iron disc suspended loosely by chains. When the tide rises it fits closely on its seat in the ironwork which is fixed in the wall, the opening being smaller than the sewer. These valves answer well; there is no flooding, and the houses and cellars remain dry.

The dimensions and costs of the sewers are as follows, all but the first being egg-shaped.

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No.	Internal dimensions.		Thickness of brickwork.	Quantity of brickwork per lineal yard.	Average depth of cutting.	Cost per lineal yard, including junctions.
	Height.	Width.				
	ft. in.	ft. in.	inches.	cubic ft.	ft.	s. d.
1	0 14	0 14	4½	5½	10	7 7
2	2 6	1 10	4½	9	10	10 11½
3	2 6	1 10	6	12¾	10	13 10
4	3 0	2 2	4½ in. with 9 in. inverts.	14 1/16	10	15 0
5	3 0	2 2	6 in.	14⅝	10	15 6
6	3 0	2 2	6 in. with 9 in. inverts.	17	10	17 2
7	3 0	2 2	9 in.	23⅝	10	22 0
8	4 6	3 0	9 in. but crown 6 in.	27 1/16	12½	28 1
9	4 6	3 0	9 in.	32 1/16	13½	31 5
10	4 6	3 6	9 in.	33⅛	15½	35 0

Prices for 10 feet depth of cutting are given for the sake of easy comparison, though many of the sewers were laid deeper. The greatest depth for 4½ feet sewers was 20 feet. The cost of the brickwork and mortar was 18s. per cube yard for 9-inch work, 18s. 6¾d. for 6-inch work, and 19s. 1½d. for 4½-inch work. Earthwork cost about 1s. 4d. per cubic yard. The brickwork was generally laid in mortar, composed of blue lias lime and clean sharp sand, in the proportion of 1 of lime to 1½ or 2 of sand. The crown of the sewers was coated outside with ½-inch thickness of mortar. Cement was used in some places for the brickwork and concrete for the foundations. For the 6-inch brickwork, radiating bricks 6 inches deep radially, 12 inches long, and averaging 3½ inches thick, were used. They were the means of effecting a large saving in many of the sewers, where otherwise two rings of 4½-inch work would have been used. For the 4½-inch work, also, radiating bricks were used.

The sewers are connected by curved junctions or bell-mouths, the curves being laid at a steeper inclination.

The subsoil in the flat part of the town—where most of the new sewers were required—is a level deposit of mud or

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clay, covered for a depth of 6 feet with ships' ballast or with clays from the docks. The construction of sewers in this flat district was easy when the ground was dry; but generally, owing to the looseness of the ballast and the water it contained, the trenches had to be well lined with planks and strutted. The planks were driven down vertically as the workmen removed the ground, while other men bailed or pumped out the water that ran in from the

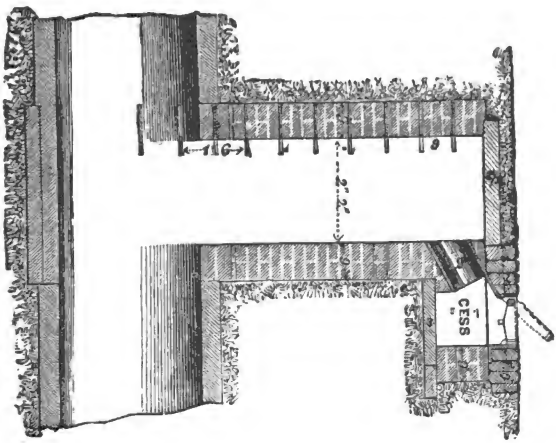

Fig. 98.—Manhole and Ventilator, Newport.

ballast or from old drains, and sometimes from the river at high tide. In one case, of a large sewer, a syphon was employed—when the state of the tide would allow—to discharge the water into the river.

The ventilation of the sewers is effected, and means of access to them secured, by a large number of manholes and ventilators combined, placed in the middle of the streets, as shown in Fig. 98. These consist of a square

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shaft carried up from the sewer to near the surface, and covered by a flagstone, and on this a thin layer of macadam. Close to the shaft a small cess is constructed of brickwork in cement, with a flagstone bottom, and is connected to the shaft by a 9-inch stoneware pipe, laid 6 inches above the bottom of the cess, and through the brickwork to the shaft. A strong iron grating, hinged, with a notched surface, is fixed over the cess. Any stones or other rubbish falling through the grate are caught in the cess. Ladder-irons are built in the brickwork of the shaft. The combined manhole and ventilator costs £4 10s., complete. This arrangement is open to the objection that the manhole shaft is not available without removing the flag which covers it, and thus breaking up the street.

During the construction of the sewers, glazed stoneware 9-inch and 6-inch pipes were inserted in the side walls, for connecting house and street drainage. Usually, a separate 6-inch drain was constructed for each house, or a 9-inch drain for two or more houses belonging to the same owner. Cesspools were cleared and filled up, and all sewage matter was passed through pipe-drains into the sewers, water-traps being placed at the commencement of the drains and in the closets. The junction-pipes not used for house-drainage, although partially stopped with a slate or a tile, afforded inlet for water, and helped to drain the subsoil below the level of the cellars.

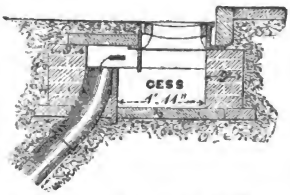

Fig. 99.—Gully-trap, Newport.

The gully-grates for street-drainage, Fig. 99, are of cast-iron, 21 inches by 17 inches at the surface, hinged, and slightly concave in the line of the bars, with a vertical diaphragm suspended at the side next the connecting pipe from the sewer, acting as a trap. The casting weighs 2¼ cwt. The connection with the sewer is made with a 6-inch pipe. The gully, grate, cess, and drain complete cost £3.

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The total cost of the work was £11,862, for which 12,500 lineal yards of sewers, with manholes, ventilators, gullies, and outlets were constructed.

The annual rate of mortality in Newport decreased from 30·3 in a thousand for several years before 1850, to less than 20 in a thousand in 1860—61. The improvement is ascribed, "under Providence, to a considerable extent to efficient drainage and water supply." In confirmation, the registrar of Newport states, in a letter dated February 13th, 1863, "the number of deaths I registered last quarter was 128, chiefly from diseases of the respiratory organs; there was not one case of fever. The mortality of Newport became much reduced immediately upon the formation of the drainage, and I estimate it to be now 22 per 1,000." In the report of Dr. Davies, Medical Officer of Health for the Borough, for the last three months of 1862, he says, "Not one death has been recorded from continued fever, which is a most remarkable immunity among so large a population, and is no doubt chiefly to be attributed to our excellent and thorough system of drainage."

VI.—Drainage of the Borough of Dundee.

Dundee, in 1863, contained a population of about 100,000 persons. It covers an area of about six square miles. Its docks cover 30 acres. Previous to 1851, the town, with the exception of three or four streets, was wholly undrained, and the sewage flowed on the surface of the streets and "closes," many of which are not more than 6 feet in width; or it was discharged into cesspools, having no other outlets than the surface channels. There was a prevailing high rate of deaths from typhus fever, and several outbreaks of cholera, with minor evils.

The sewerage of the town was commenced in 1856, and completed in 1862, at a cost of £52,000. The site of the town, on the estuary of the Tay, is slightly embayed, comprising a level tract of clay, silt, and gravel, backed by a

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rising ground, in which the gradient of several streets is 1 in 7. The highest portion of the town stands 300 feet above the mean tide level.

One of the old sewers was constructed by the Harbour Trustees to intercept the drainage of the town, and prevent it from entering the docks or the tidal basin. It extends the whole length of the harbour, about 1,600 yards, and runs nearly parallel to the river. It has a fall of 1 in 400, or 13 feet per mile, and its average depth below the surface is 15 feet. Its outfall is 21 feet below the level of the quay, or 8 feet below the level of mean tide. It is built of rubble masonry, rectangular in section, 7 feet high, 3 feet 9 inches wide. This sewer is the principal outlet for the drainage of the town sewage and flood waters. It drains about 1,000 acres of surface. The dry-weather discharge of sewage is 2 feet deep, with a velocity of 65 feet per minute, which rises to 6 feet during storms, and a velocity of 116 feet per minute. Another outlet, egg section, 3½ feet by 2¼ feet, drains a suburb of about 4,000 persons. A third, 4½ feet by 3 feet, is required for flushing purposes, and acts as a relieving sewer during floods.

The whole of the drainage, so far as was practicable, has been carried to the first and main outfall. It is discharged at once into deep water, where the river is a mile broad, and is speedily dissipated in the stream. The sewerage is a combination of brick sewers and salt-glazed fire-clay socket-pipes. The brick sewers, of the egg form section, shown in Fig. 100, page 305, are laid in the leading thoroughfares. All converge to a point in the centre of the town, and this fact has been taken advantage of in regard to the main outlet. The streets drained by pipe-sewers are chiefly those at right angles with the river, which are the steepest and the most suitable for pipe-sewers. The joints of the pipe-sewers were made with clay. The sectional dimensions of the different sizes of sewer are as follows:—

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	Height.	Width
Brick Sewers	3 ft. 0 in.	1 ft. 10 in.
,,	3 ,, 6 ,,	2 ,, 3 ,,
,,	4 ,, 0 ,,	2 ,, 9 ,,
,,	4 ,, 6 ,,	3 ,, 0 ,,

	Diameter.
Pipe Sewers	9 in.
,,	12 ,,
,,	15 ,,
,,	18 ,,

The average depth of the sewers below the surface is 12 feet—considered necessary in order to secure proper drainage of the cellars. The depths varied from 7 feet to 21 feet. The deepest cutting, in trap rock, was 19 feet. The total quantity of rock excavated was 24,000 cubic yards, the greater portion of which was removed by means of gunpowder. It was even necessary, in some cases, to use gunpowder inside dwelling-houses, in the formation of branch drains. By using only small quantities of powder for each shot, and covering and loading the rock, casualties were prevented. Running sand occurred in many places. In one lane, not more than 9 feet wide, with ponderous buildings on each side, having their foundations near the surface, a bed of this sand was met with at a depth of 9 feet. The sewer in this case was of large dimensions, and at a level of 12 feet below the surface, but by shoring the buildings and using cofferdams, all injury was obviated. But in this and in many other instances it was necessary to leave nearly the whole of the timber lining in the trenches. In several streets, when the subsoil was sufficiently solid, tunnelling was resorted to; but this was found unsatisfactory, and was given up, because of the uncertainty of securing thorough consolidation of the spaces to be filled up over the arches or the pipes. The numerous gas-pipes and water-pipes were a source of great annoyance and expense.

The leading or intercepting sewers are from 12 inches

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to 18 inches deeper than the lateral and branch drains, in order to prevent silting of these drains. In sewers of little fall, sand speedily accumulates. But the quantity of sand and the time in which it is deposited are materially influenced by the quantity of water passing through the sewers. With a fall of 1 in 600, or 8·8 feet per mile, the earthy and more soluble matters are carried off by the ordinary rainfall and sewage; but a deposit of coarse sand is left behind in all sewers having no greater fall than that. The minimum fall is 1 in 700, or 7·5 feet per mile.

Of brick sewers, 10 miles were constructed, and of pipe-sewers 20 miles, making together 30 miles of sewers. The cost of the two classes averaged 33s. per yard and 13s. per yard respectively.

Manholes, with 9-inch brick walls, have been constructed at intervals of 40 yards along each sewer, and at junctions. They are provided with cast-iron covers, having frames 8 inches deep to match the paving setts, and grooved lids hung on wrought-iron axles. Projecting bricks alternately on opposite sides of the manholes serve as ladders.

The brick sewers are provided with invert blocks of glazed fire-clay, 30 inches in length. The walls and arches are 9 inches thick, the latter being turned with two rings of half brick. In wet or yielding subsoil, the invert-blocks were laid on concrete. When exposed to the influx of the tide, the side walls were built in Roman cement.

Junctions of sewers are illustrated by Fig. 100. They are formed at acute angles, in order that the combining currents may not baffle each other.

Gully-drains are placed at intervals of from 30 to 60 yards apart, being closer together in the steepest streets. They are for the most part made with 6-inch faucet-pipes. In the streets, in the level part of the town, they are made with 9-inch pipes. The sewer gases are prevented from escaping through the gullies by stone valves, hung with copper links, on one side of a small cess-

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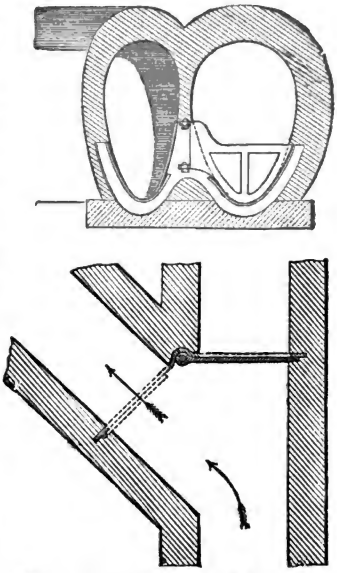
pool, Fig. 101. The bottom of the cesspool is 10 inches lower than the lower side of the valve, and stones and other matter falling in are trapped. The gully-drains are intended for the reception of rain-water only, the cess-pools being cleansed weekly during the prevalence of wet weather. They freely pass the water, and retain the heavier road detritus. The stone valves have a fine grain, and with a 2-inch overlap on the opening, properly polished and adjusted, they are capable of resisting a considerable head of pressure, and remain perfectly watertight.



Figs. 100.—Junction of Sewers.

The branch drains have in all cases been made with stoneware pipes, of from 4 inches to 12 inches in diameter. Where they are connected with the sinks and water-closets in houses, they have no other traps than those of the syphons which are placed in immediate contact with sinks or water-closets. Underground cellars, near the level of high tide or the water-run of the public sewers, and having branch drains into these, are provided with self-acting flap-valves of stone, like those used in the gully-drains.

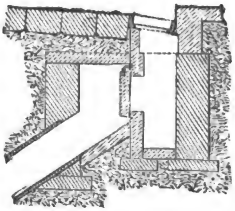


Fig. 101.
Gully-trap, Dundee.

The flushing of the sewers is effected by intercepting the

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sewage at any suitable point by means of a cast-iron gate, and turning it into any sewer, or special series of sewers. The various levels have been taken advantage of for this purpose, and by means of a series of gates of this description, placed at the junction of the sewers, as in Fig. 100, and immediately under manholes, giving ready access to them, the greater portion of the sewers have been rendered self-cleansing. As already stated, in sewers having little fall, of, say 1 in 600, or 8·8 ft. per mile, there is a tendency to accumulation of sand; and in pipe-drains with even greater fall than this, where the ordinary house-drainage only exists, sand also accumulates. The flushing-gates, shown in Fig. 100, are only 15 inches deep, and they answer the purpose of overflow weirs, preventing the sewer during floods from being subjected to undue pressure, by allowing the surplus contents to flow into subsidiary outlets.

When a sewer is to be cleansed, a windlass containing 45 yards of chain is placed over each of two adjacent manholes. A series of tubes, or hollow rods, each 4 feet in length, extending to 40 yards, with screwed ends to fit together, is then put together at the bottom of the manhole, and is pushed by hand to the next manhole, where the rods are unscrewed as they are drawn through. The chain is attached to the last rod, and is by this means carried along the sewer, and fixed to the cleansing tool in connection with the other chain and windlass. Horizontal and vertical bars of iron with clamping screwed slides, to suit any size of sewer, are then fixed, the vertical bars having iron pulleys on their lower ends with hinged openings, through which the chain is passed. As the matter to be removed from the sewer usually consists of hard sand, a tool is first attached to the hooks of the chain, in order to plough or break it up. A scraper formed of strong flat iron is next drawn through, backward and forward, several times. The stuff removed is hoisted to the surface. The cost of cleansing sewers on this system is 2d. per lineal yard for brick sewers and 1d.

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for pipe sewers. Sewers require to be cleansed about once in twelve months.

It is a question whether it would not have been better and more economical to have paid the water company for a proper supply of water, and to have depended upon that for scouring power.

VII.—Drainage of Hamburg.

The sewerage of Hamburg, designed by Mr. W. Lindley, is worthy of notice. It was executed upwards of thirty-five years ago. The most striking feature of the system is the means of constantly flushing the sewers, which are kept so clean that it is rarely necessary to send any men into them except for the purpose of making repairs. There is a syphon sewer passing under the canal, which is kept clean by flushing with as much apparent facility as the sewers with a regular fall. The forms and dimensions of the sewers vary with their inclination, as well as with the quantities of sewage which they were designed for carrying off. The steep sewers are cylindrical, from 15 inches to 20 inches in diameter, and their fall varies from 1 in 15 to 1 in 150, or from 352 feet to 35 feet per mile. Four or five miles of such sewers have been laid. For long main lines when such rapid falls could not be obtained, oval sewers of large dimensions were built, sufficiently large for men to pass through, being 4½ feet high and 2¼ feet wide. This class of sewer was not made with less inclination than 1 in 500, or 10 feet per mile, in the upland district of the city, where the quantity of water to be obtained for flushing is dependent upon the waterworks. But in the marsh districts, where the water for flushing is obtained from the river Alster, sewers of this description are laid as nearly level as an inclination of 1 in 3,000 or 1·76 feet per mile. The marsh land would not allow of a greater fall, and the unlimited flushing power derived from the river rendered the adoption of such

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low gradients quite unobjectionable. Every house has its drain-pipe discharging directly into the sewers without any cesspool. Where there is fall enough, a 6-inch iron pipe is carried directly into the opening built in the sewer to receive it; but where there is less fall, the brick drains of 12 inches or 15 inches in diameter receive the soil-pipes within the house and discharge the contents into the main sewer.

The larger classes of sewers follow each other in succession, as the number of smaller sewers are united and the quantity of water to be carried off increases. The largest sewer is 5 feet wide and 6 feet high. During heavy storms of rain, the quantity of water delivered into it from all its tributaries is so great that it has, on a few occasions, been filled nearly to the soffit.

The whole of the upland sewers were so laid out as to act as catch-water drains, and thus to separate the upland waters from the marsh sewers. This arrangement was necessary, because the water in the Elbe remains at times from 24 to 36 hours above the cellars of the houses. The upper ends of all the sewers are connected either with the river Alster, which affords a head of 13 feet of water, or with the canals by which the city is intersected, or with other high-lying sewers, the latter forming reservoirs supplied from the waterworks. Thus there are not any dead ends, and all the sewers can be thoroughly flushed from one end to the other. By this arrangement, it is true, additional outlay was incurred for extra length of sewers to form the connections with the water-heads, and for penstocks and flushing-gates to turn the stream in the direction required through the sewers. But the general result of this through system of flushing is great economy in working; and it is proved that the cheapest means of getting rid of the matters discharged into the sewers is to dilute them with large quantities of water, and then to flush them away.

There are two outfalls for the sewage of Hamburg, one for the upland waters and the other for the lowland waters.

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The two discharges are delivered into the main stream of the river Elbe at a point below the city and the harbour, so selected that steam engines may be placed to pump the sewage-water over the lands of the adjoining district, when such a proceeding may be deemed advisable.

A district of the city is so situated as not to be susceptible of being drained by self-cleansing sewers, and the main object of the system was to prevent all accumulations of filth within the sewers, keeping them clean by repeated flushing from a head of water. The experience of many years has shown that this plan is both practicable and economical. Animal and vegetable refuse being in this manner washed away before decomposition can take place, poisonous gases are not evolved, and the atmosphere of the sewers, by the aid of a system of ventilation, is kept in an innoxious and healthy state. The extent of the flushing power is evidenced by the experiment of putting a large cast-iron ball into the sewer dipping under the Alster on the higher side. It is forced out in the opposite direction by the head of water.

VIII.—The Main Drainage of Paris.

When, in 1808, the subject of the main drainage of Paris first received systematic investigation, the "great" or main drain, was only a large natural ditch—the brook of Menilmontant converted into a ditch or open sewer. As early as the year 1412, this brook is mentioned as having been used for the purpose. In 1740, this ditch was walled and arched over. It was assumed in 1808 that the drains should empty themselves into the Seine, following the undulations of the streets. The river within the limits of the city was made the main receiver of all the sewage. From both banks and from the central islands all outlets poured directly into it, and at the end of 1837 there were probably forty independent outfalls. By the more recent

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developments, all these outfalls were, with three exceptions, abandoned, and longitudinal intercepting drains of a large section, running parallel to the river, were substituted, and the drainage was collected at four points of discharge, namely, Asnière, Chaillot, the Island of St. Louis, and the Island of Notre-Dame, in addition to which, in 1863, 217 miles of main sewers had been constructed in Paris. In January, 1874, a total of 356·7 miles had been constructed, and it was then estimated that 286·8 miles, mostly in the suburbs near the fortifications, remained to be constructed to complete the whole system, making a total length of 643½ miles.

The drains are confined to the carrying off of rain-water and household water. Night soil has no connection whatever with the drains. It is carted away from the city and deposited at appointed places. Road-scrapings find their way into the drains. Besides, the sand which is stored in heaps along the streets for purposes of repair is converted into a mud, which, with the road-scrapings, is not uncommonly swept into the drains. In many cases the inclination of the drains is so slight that they can hardly carry off the solid matter, which, in fact, is deposited, and must be cleared away by mechanical means.

The principle thus adopted by the French engineers for the drainage of Paris differs materially from that of London and the practice of English engineers. In England the egg-shaped sewer and peculiar form of invert has been adopted as being the best for self-cleansing and carrying either a maximum or a minimum quantity of sewage. In Paris also the oval-shape has been adopted, but the invert is nearly flat, forming the *radier* or floor, of a breadth varying from 16 inches to 24 inches. This modification, in connection with the great height of the sewer, at least 6 feet, was adopted in order to allow workmen to enter and cleanse even the smallest sewers.

In streets of a width greater than 65½ feet, double lines of sewers are constructed, one under each footpath, to limit

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the length of the branch-drains, which are laid at the expense of the proprietors.

The main intercepting sewer of the south side, "Grand Égout Collecteur de la Rive Gauche," is of the type No. 3, Fig. 102. It commences at the Boulevard St. Marcel, Jardin des Plantes, and terminates at the syphon of the Pont de l'Alma, 10 feet above the lowest water-level of the Seine. It is 6,015 yards, or 3·42 miles, in length, with a fall of 1·8 feet to the mile, or about 1 in 3,000; the total fall being 6·17 feet. At the Pont St. Michel and Place St. Michel there is a large vaulted chamber with a storm-water outlet to the lower quay of the river. It is proposed to extend this sewer from the Boulevard St. Marcel to the fortifications, to replace "La Bièvre," a stream, the bed of which has been made into an open drain 11½ feet broad, 6½ feet deep, to receive both the surface-water and the refuse-water from the tanneries, the Gobelins, and other manufactories. This stream formerly entered the Seine at the south-east side of the Jardin des Plantes, but it is now intercepted at the Rue Geoffroy St. Hilaire by the main intercepting sewer of the south side.

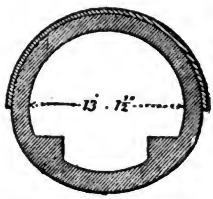

Fig. 102.—Intercepting Sewer, Paris.

The cleansing of this sewer is effected by means of a flushing boat. The main branch-sewers intercepted by it are all cleansed by flushing trucks.

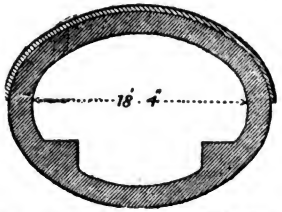

Fig. 103.—Intercepting Sewer, Paris.

The main intercepting sewer of the north side, "Collecteur Général de la Rive Droite," is of the type No. 1, Fig. 103. It commences at the Boulevard Sebastopol and terminates at Clichy, opposite

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Asnières. The fall of the sewer varies from 1 in 798 to 1 in 2,766, or 6·6 feet and about 2 feet per mile. It passes under the Boulevard Courcelles at a depth of 77 feet, and under the fortifications at a depth of 33 feet.

There are sixteen vaulted chambers in the sewers of the north side, and five in those of the south side, used as places of rendezvous for the workmen, and as store-rooms for tools, boots, &c. Of these chambers, four have direct outlets on the quays bordering the Seine —the Place du Châtelet and Pont de l'Alma on the north side, and Ponts St. Michel and de l'Alma on the south side. The opening at the Pont de l'Alma, at the head of the syphon constructed to pass the sewage of the south side to the north side, is more used than the others for discharging the deposit from the sewers into barges on the river. But, as a rule, and except after extraordinary floods, the deposit is entirely removed by the flushing boats and trucks.

Ventilation of the sewers is only effected by the outlets in the large chambers on the Seine, and through the gully-holes in the sides of the kerbstones of the pavements, the openings of which have an area of three square feet, and are connected directly with the sewer by a side shaft, without any kind of trap. The sewers and gullies are free from bad smells; but the streets and gutters are swept and well washed with water twice a day. The main sewers bear the names of the streets under which they run, and the house-drains the number of the houses which they serve.

The syphon of the Pont de l'Alma, for conveying the sewage of the south side to the north side, across the Seine, is composed of two wrought-iron tubes $3\frac{1}{4}$ feet in diameter, $\frac{3}{4}$ inch thick. The tubes are each $556\frac{1}{2}$ feet in length, of which the portion between the two masses of masonry at the ends is $511\frac{1}{4}$ feet long. It has a minimum head of 1·7 feet—the difference of level between the south side and the north side; but the head can be increased to 7·8

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feet. An effective system of scouring can thus be practised. A wooden ball, 33½ inches in diameter, weighing 187 pounds, is sent through the tubes once a week. As it is about 6 inches less in diameter than the tube, it rolls along the crown of the tube, and should its course be arrested by deposit, an additional scouring takes place under the ball, and the sediment or accumulation is dislodged and removed. With a head of 1.7 foot, the calculated time for the passage is 2½ minutes, the velocity being at the rate of 3·60 feet per second. The results of several trials showed that the ball took, on the average, from 2 to 2½ minutes to pass over. It seldoms happens that much deposit is brought out; but on the 10th December, 1868, after heavy rain, the ball occuped 11 minutes in passing, when it brought out large quantities of dung, mud, and gravel. On another occasion, it remained a quarter of an hour in the syphon, and brought out several pieces of hide—coming, probably, from the tanneries bordering La Bièvre. There is an inclined grating at the head of the syphon, which is continually being cleaned. The calculated volume of discharge under a head of 1·7 feet is 205 gallons per second, and it is estimated that from 109,000 to 127,000 cubic yards of sewage pass through each tube every twenty-four hours. One tube at a time is more than sufficient to convey the average sewage of the south side, but during heavy rains both tubes are used. One of the heaviest falls of rain on record at Paris took place July 27, 1872, when an average depth of 1·72 inches fell over the city in the course of an hour. This caused a rise in the lower part of the sewer Sebastopol, at its junction with the Rivoli sewer, of 4·1 feet above the level of the "banquettes," or sidewalks; and in the higher part, at its junction with the sewer of the Boulevard St. Denis, of 6·2 feet. On March 17, 1876, the Seine rose to the level of 18·8 feet above the invert at the outfall of the main sewer at Clichy. The sewage was, therefore, during fifteen days backed up into some of the lower parts of

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the city. The only inconvenience occasioned was that a considerable quantity of silt and sand had to be removed by hand after the waters had subsided, before the channels could be cleansed by the flushing trucks and boats.

With regard to the mechanical means by which the deposit in the sewers is removed. Before the introduction of the mechanical contrivances now in use, several drains were laid at an inclination of 1 in 1,000, or 5·28 feet per mile. The slope was insufficient for carrying off in suspension all the solid materials of the drainage. Cleansing, then, where attended to, was done by hand labour, assisted by flushing. Rakes or scrapers of wood, cut to the contour of the invert, were worked backwards and forwards, until all the mud had been drawn to a point under one of the working shafts, through which it was lifted. This operation was chiefly confined to the smaller class of drains. In the larger drains the brush and rake were used, assisted by a shutter turning on a horizontal pivot or spindle on the upper edge, and lying across the drain. This shutter being retained in a vertical position by the back pressure of the water, acted as a dam, and on a sufficient head being obtained it was opened, and the rush of the water carried all before it.

For the larger drains a cleansing boat is now used, furnished with a large scraper at its bow-end. The scraper nearly fills the section of the waterway, and is capable of motion in a vertical arc. It can therefore be lowered till it touches the invert. It is lowered by crab-gearing till its head dips into the mud. It then forms a dam, behind which the water gradually rises, and forms a motive-power by which the boat is pushed forward, carrying the mud with it. Some of the smaller drains are cleaned by means of a small truck, which is used with an apparatus like that of the boat.

The maximum and the minimum temperatures of the sewage-water, in 1876, with those of the river Seine and the atmosphere, were as follows:—

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	Maximum.	Minimum.
Sewage . . .	72·5° F.	36·5° F.
Seine	77·0	33·0
Atmosphere . . .	82·4	15·8

For flushing and cleansing the sewers of Paris, a sum of £38,000 is allowed yearly for wages, tools, boats, and working expenses. Including general charges and cost for repairs, the total amount is £44,000.

The total cost of the main drainage of Paris is estimated by Mr. F. Target at about £4,000,000, for an area of about 30 square miles, in which there are 355 miles of main and branch sewers, and 123 miles of branch drains for gullies, access culverts, and subways connecting the basement of the houses to the drains.

The greater part of the excremental matter is drained into cesspools not connected with the sewers, and it is pumped thence into cylindrical iron carts. These, when filled, are hermetically sealed and conveyed to the several depots. The more modern system is that of the movable receptacles (*appareils diviseurs* or *tinette filtres*), sheet-iron cylinders for separating the fluid from the solid portion of the excreta. The fluid is either discharged into cesspools, or is sent into the sewers.

There were in 1878 about 70,000 houses in Paris, of which only 62,000 were registered as having some description of night-soil service. These comprise four systems:—

	Number.
1st. Watertight cesspools built in masonry .	86,000
2nd. Movable receptacles or wooden barrels .	17,450
3rd. Movable receptacles in which the liquid portion only filters into the cesspools . .	10,770
4th. Movable receptacles in which the liquid portion only filters into the sewers . .	10,000
	124,220

The sewage of Paris is partially utilised in irrigating the plain of Gennevilliers, where there are about 15½ miles of sewage carriers. The following comparative statement of the produce per acre on irrigated land, and land not

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irrigated, gives a good idea of the value of sewage irrigation on such poor soils as those of Gennevilliers.

	Irrigated land.	Land not Irrigated.
Wheat	30 to 55 bushels	$38\frac{1}{2}$ to 65 cwt.
Green Rye	122 to 210 cwt.	
Green Lucerne.....	492 to 923 cwt.	84 to 131 cwt.
Rye Grass.....	1,023 cwt.	
Mangold Wurzel.....	892 cwt.	369 cwt.
Potatoes	687 to 797 cwt.	453 bushels.

IX.—The Main Drainage of the Wandle Valley.—Sewage Irrigation.

The Wandle Valley Main Drainage works, constructed for the Croydon Rural Sanitary Authority, to the designs of Mr. Baldwin Latham, embraces the construction of about 55 miles of main sewers, with outfall works, for the collection and disposal for filtration of the sewage of the parishes of Mitcham, Beddington, Merton, Morden, Wallington, and the special drainage district of Merton Rush, Surrey. The system applies to an area of 10,106 acres, with 17,000 population. About one-fourth of the area is within the watershed of the Beverley Brook, and the remainder in that of the river Wandle.

The outfall works are situated in the valley of the Beverley Brook. Previous to the construction of the works, the sewage passed directly to the Wandle and the Beverley Brook. The contract for the works was let in 1878, and comprised the construction of 36 miles of main sewers, the outfall works, pumping-station, screening tanks, sludge presses, an iron bridge over the Wandle, two cottages, and the preparation of a filtration area of 28 acres in extent. In the course of the work of construction, new roads were constructed, and ultimately the length of sewers constructed reached to nearly 55 miles, of which 4 miles were constructed in tunnel.

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The scheme carried out is essentially one of separation of the sewage proper from the rainfall; the rainfall from the streets and roofs of houses being, as far as practicable, diverted into the old sewers, drains, and watercourses. As much of the sewage as possible is brought to the land by direct gravitation. The sewers are, with a few exceptions, constructed in straight lines between manholes, or lampholes; and a manhole is constructed at each junction of branches with main sewers, the sewers being inclined to give a minimum velocity of 2½ feet per second where small, and 2 feet per second where large. The sewers may be flushed from every dead end, and flushing-wells are constructed at various points, when the subsoil contains sufficient water. The wells are near a manhole, and are each provided with a sluice-valve, on opening which the contents of the well are discharged into the sewer. The manholes are constructed with gault bricks formed to the radius. The outlet from each manhole is provided with a stoneware flushing-block. The inlets are provided with a balance-valve, in order to prevent sewer-gas from passing to the higher parts of the district. Junctions of branch sewers with the main sewer, when the latter is at a much greater depth than the former, are made on an incline of 30°, as in Fig. 104, flowing into a bend at the bottom, which forms a trap. The object of this disposition is to obviate the disengagement of foul air from sewage which takes place when it is allowed to drop vertically. For the purpose of inspection, the sewer is also carried into the manhole at its proper gradient, as shown in the figure.

The greater part of the sewers are constructed of stoneware pipes, of from 9 inches to 18 inches in diameter, of the kind known as "London made." Junctions for house-drains are inserted at intervals averaging 50 feet. The sewers were treated in various ways externally, to prevent the leakage into them of subsoil water. As a rule, they were jointed with tarred gasket and Portland cement. In

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moderately wet ground, puddled clay was worked around on the outside of the cement fillet. In gravel containing large volumes of water, the pipes were protected with 6 inches of Portland-cement concrete, made of 1 part of cement to 6 parts of ballast. Pipes laid at depths exceeding 16 feet were likewise treated, to prevent their being crushed by the superincumbent earth. Lengths of sewers 15 inches and upwards in diameter were constructed of rock-concrete tube, which compares favourably in strength

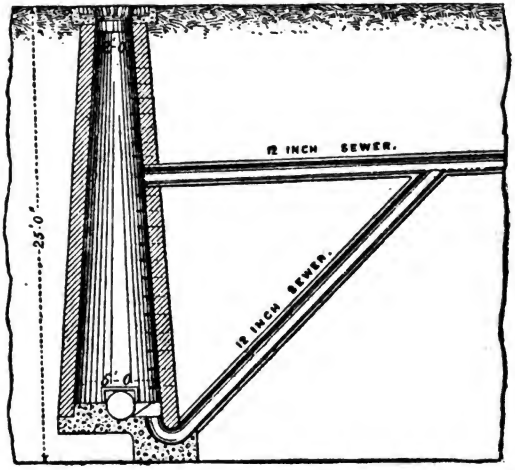

Fig. 104.—Junction of Branch and Main Sewers at different levels.

and ease of laying with stoneware pipes. The observed rate of leakage, in the case of sewers laid in wet ground, was 1 cubic foot of water per mile per minute. Sewers 24 inches and 27 inches in diameter are constructed with one ring of brickwork, a collar joint of cement mortar, and 6 inches of cement. Four-feet sewers are of two rings of brickwork, with a cement collar-joint between the rings.

The 15-inch outfall at Wallington was constructed with

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iron pipes, as stoneware pipes were found impracticable in the heavy discharge of water which took place. A mile of sewer was thus constructed. At crossings of the Wandle and the railways, iron pipes were substituted for earthenware, and brickwork sewers were strengthened by an additional ring of brickwork. There are 20 miles of 9-inch pipe sewers.

In the lower parts of the district, storm-water overflows are provided for the relief of the outfall sewers in cases of accident, and also for use during periods of heavy rainfall. A storm-water culvert for the relief of the Gaveney is 350 yards in length, 8 feet wide, 5 feet high, with a segmental arch and invert.

The gravitation outfall is 27 inches in diameter, with a fall of 1 in 1,200, or 4·4 feet per mile. The low-level outfall is 18 inches in diameter, with a fall of 1 in 900, or 5·87 feet per mile. It ends in a "tank-sewer," 4 feet in diameter, with a fall of 1 in 1,000, or 5·28 feet in a mile. The contents are discharged at the pumping station. The sewage from the low level is pumped up into the gravitation outfall, and the whole then flows through the depositing tanks.

The sewage is lifted an average height of 20 feet into two tanks by a pair of horizontal rotative condensing pumping steam engines, constructed by Messrs. Hathorn, Davey & Co., having 12-inch cylinders, with a stroke of 20 inches, with expansion-valves. The pumps, designed by Mr. Latham, have each a piston and a plunger, 22½ inches and 16 inches in diameter, with a stroke of 20 inches, making 20 turns per minute. The engines also work the lime-mixer and the agitator for mixing the lime with the sludge.

In the depositing tanks the sewage is deprived of floating matter by means of planks on edge, and the deposition of suspended solids is aided by the cross walls, over and under which the sewage passes before it is finally filtered through a bed of coke, 4 feet thick, whence it passes to the

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filtration area for final purification. The deposited sludge is swept into the sludge-pit on opening the penstocks. In the mixing-well the milk of lime is added to and mixed with the sludge; thence it is passed through the filter-presses under compressed-air pressure, when the fluid is separated from the solid, the latter being formed into cakes in the press. Thirty-four cubic yards of raw sludge are yielded by the tank per week. The lime added is 4 cubic yards, or 20 cubic yards as milk of lime, making in all 54 cubic yards of treated sludge weekly, which is reduced by pressing to 12 cubic yards of cake, containing 50 per cent. of moisture. The usual air-pressure employed is 40 lbs. per square inch.

For the final purification of the sewage, an area of about 40 acres of land and water was purchased. It is divided into two portions, 29·6 acres and 9 acres, by the Wandle. The first portion has been laid out for the purposes of sewage disposal, 28 acres being available for sewage purposes. The subsoil consists of marsh clay, gravel, sand, and alluvium. It overlies the London clay, and is in places 17 feet in thickness. It is surrounded by a clay-puddle wall or dam, as it lies low. The wall is 2 feet thick, and is taken down to and a foot below the surface of the London clay. The filtration-area is about 1,000 yards in length and 140 yards in breadth. A road was made through the whole length of the area, down the centre. The main drain, 2 feet in diameter, is constructed under the road. There is also a drain inside of the puddle wall, parallel with the main drain, and distant 70 yards from it, and connected to the main drain at intervals of 400 feet, thus dividing the filtration into separate sections of about 400 feet by 210 feet. The average depth of the drains is 6 feet, defining 271,040 cubic yards of filtering material enclosed within the puddle-wall, or 15·94 cubic yards of filter per head of the population. Near the works some good houses are situated, and, to prevent unpleasantness to the occupants,

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an area of 2 acres of the land adjoining the works is laid out specially. The sewage is applied below the surface by means of 9-inch perforated pipes, 16½ feet apart, leading out from the main carriers. The space between the pipes is filled in with a bed of screened gravel, in order that the sewage may be evenly distributed over the entire surface of the natural filter below. The bed of gravel is covered with soil 18 inches in thickness, on which all kinds of vegetables are grown. The remainder of the filtration area is, in consequence of the large volumes of sewage dealt with, wholly devoted to the cultivation of rye grass, for which there is a good demand, the crops realising about £30 per acre per year. The greater part of it—21 acres of the filtration area—was merely under-drained and carefully levelled. The drains vary from 210 feet to 16 feet apart, according to the requirements of the different soils.

The main carriers for the distribution of the sewage nearly surround the filtration-area. That on the western side is of concrete, and that on the eastern side is of 18-inch stoneware pipes. There are outlets from each carrier at intervals of 33 feet, the sewage flowing into subsidiary earth-carriers, whence it is distributed over the surface of the land. The outlets are provided with regulating shutters of wood, working in stoneware blocks with ground faces. An artesian well for general service was sunk to a depth of 230 feet; 6 inches in diameter, lined with cast-iron pipes to a depth of 200 feet. The details of the strata passed through are as follows :—

	feet.	
Alluvium	12	Depth to chalk 179 feet.
London clay	80	
Woolwich and Reading beds . .	40	
Thanet sands	47	
Into the chalk	51	

The total cost of the works, with the land, was £123,000. The following are extracts from the schedule of prices :—

Excavation.—Excavation for sewers 5 feet 8 inches outside

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diameter, including timbering and pumping, trench taken as if 6 feet in width.

Average depth. feet.	Price per cubic yard. s. d	Refilling and Punning per cubic yard. d.
22	2 2	3¼
23	2 2½	,,
24	2 3	,,
25	2 3½	,,

Trench as above, 4 feet wide.

Average depth. feet.	Price per cubic yard. s. d.	Refilling and Punning per cubic yard. d.
5	1 5	3¼
6	1 5½	,,
7	1 6	,,
8	1 6½	,,
9	1 7	,,
10	1 7½	,,
11	1 8	,,
12	1 8½	,,
14	1 10	,,
15	1 10½	,,
16	1 11	,,
17	1 11½	,,
18	2 0	,,
19	2 0½	,,

Trench as above, 3 feet wide, for pipe sewers.

Average depth. feet.	Price per cubic yard. s. d.	Refilling and Punning per cubic yard. d.
3	1 5	3¼
4	1 5	,,
5	1 6	,,
6	1 6½	,,
7	1 7	,,
8	1 7½	,,
9	1 8	,,
10	1 8½	,,
11	1 9	,,
12	1 9½	,,
13	1 10	,,
14	1 10½	,,
15	1 11	,,
16	1 11½	,,
17	2 0	,,

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Increasing ½d. per cubic yard for every foot in depth down to 33 feet.

Surplus Earth.—10½d. per cubic yard. Contractor found all shoots.

Making good Surface of Roads.—3½d. per cubic yard.

Pipe Sewers, laid as described.—9 in., 2s. 9d.; 10 in., 3s. 5d.; 12 in., 4s. 0½d.; 15 in., 7s. 1½d.; 18 in., 9s. 4d. per lineal yard.

	£	s.	d.	
Average cost of manholes . . .	19	12	0	each.
Do. of combined ventilators and lamp-holes	6	15	0	,,
Flushing wells	32	12	0	,,
Storm overflows	15	6	0	,,
Engine house, pumping and other machinery, sewage tanks, boilers, chimney shaft, two cottages, and fencing	8,100	0	0	,,

Filtration Works.

	£	s.	d.	
Sub-irrigation plots, complete . .	622	0	0	per acre.
Artificial filters, complete . .	750	0	0	,,
Cost of natural filters :—				
Proportion of puddle wall (9s. 3d. per lineal yard)	40	8	0	per acre.
Do. roads	13	0	0	,,
Do. drains	67	6	0	,,
Do. carriers (permanent) . .	71	0	0	,,
Do. levelling	30	0	0	,,
	£221	14	0	

	Acres.
Area of district drained by gravitation sewers . .	8,226
,, ,, pumped ,, . .	1,880
Population draining into gravitation sewers . .	15,500
,, ,, pumped ,, . .	1,500

X.—The Drainage of Abingdon.—Sewage Irrigation.

The sewage works of Abingdon were designed by Mr. Bailey-Denton for a prospective population of 10,000 persons. The dry-weather sewage was estimated at 25 gallons per day per head, or a total of 250,000 gallons per day. He advised the acquisition of 20 acres of land on the banks of

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the Thames, about three-quarters of a mile below Abingdon, for the purification of the sewage by intermittent downward filtration, combined with wide irrigation. The drainage area comprised within the boundary of the borough is about 287 acres, of which 200 acres may be taken as tributary to the sewerage system. The surface of the ground is slightly undulatory, rising gradually from the river Thames on the east, and from the river Ock on the south. The soil is sand and gravel, with occasional beds of clay. The local levels above Ordnance datum are as follows:—

	Feet.
Ordinary summer level of the Thames	162
Ditto, in floods	167
River Ock, kept up for working mills, to	168
Higher parts of Abingdon	200
Lower parts of Abingdon	168 to 175
Land for purification	165 to 168

The sewers in Abingdon, when Mr. Denton made his report in 1874, were inadequate. Those then in use consisted, for the most part, of culverts 18 inches or 24 inches in diameter and 4½ inches thick; while, in one street, a watercourse was arched over and used as a sewer. What was wanting in sewers was made up by cesspools.

The whole of the sewage was carried to a pumping station, and there lifted to the height necessary for the command of the entire surface of the land selected.

The following is a summary of the principles adhered to in designing the sewerage system:—Surface-water was excluded from the new sewers as far as possible, retaining the existing sewers for surface drainage, except the rainfall on back roofs and yards, which was admitted into the new sewers. The level of the subsoil water in Ock Street and the low neighbourhood was reduced as much as possible by laying open drains beneath the sewers, or in other places, so as to render the foundations and cellars of buildings dry and healthy. Storage capacity was provided to hold the night-flow of sewage. The storage-reservoir was placed outside the inhabited district, with provision,

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by air-shaft and check-valves, to prevent sewer-gas from being driven upwards towards the town. By means of one or more storm-overflows, the sewage was not allowed to head back above a given height in the outfall sewer, which it must otherwise have done on occasions of heavy rains, floods, or accident to the engines. All the sewers were made water-tight, so as to prevent the ingress of subsoil-water, which would in some parts of the town have greatly increased the quantity of diluted sewage to be pumped. All the pipe-sewers were laid in straight lines, and at each change of direction or inclination, and sometimes at intermediate points, air-shafts were constructed, so as to ventilate and provide for the inspection of the entire sewage system. The town being without a public water-supply, provision was temporarily made for flushing the sewers by inlets from the Thames, the Ock, and other streams. As the work proceeded private connections were made with the new sewers by the contractors, and old connections cut off. All cesspools were filled up when the works were sufficiently advanced to receive the sewage and to discharge it upon the land. The engine-power is in duplicate, and each engine is capable of lifting 50 per cent. more than the sewage when undiluted with surface water.

The portion of the outfall sewer which acts as a reservoir is 3½ feet in diameter and 500 yards in length. It has a capacity, with that of the pump-well chamber, of 100,000 gallons, being over one-third of the prospective dry-weather sewage. The main sewer from the reservoir to the town is 18 inches in diameter. It is capable of discharging 2,000,000 gallons in twenty-four hours, or eight times the estimated dry-weather flow. The secondary sewers are nearly in proportion to the outfall sewer, consisting of 15-inch, 12-inch, and 9-inch pipes.

The level of the invert of the sewer at the pumping station is 154·3 feet above Ordnance datum, or about 8 feet below the ordinary summer level of the Thames. From the pumping station, the sewer rises with a gradient of 1 in 880,

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or 6 feet per mile, for the length of the reservoir. Thence the 18-inch sewer is laid on gradients of 1 in 754 and 1 in 528, or 7 feet, and 10 feet per mile. A storm overflow is placed at the pumping station, at a level of 162·5 feet above Ordnance datum, or 6 inches above the ordinary level of the river.

The outfall sewer, Fig. 105, is constructed with two rings of brickwork surrounded with at least 6 inches of concrete. The concrete was made in the proportion of six parts of gravel and sand to one part of cement. A ring of cement is laid between the brickwork and the concrete, and another between the two rings of brickwork, to render the work watertight. The cement was mixed with an equal portion of clean sand. Six inches beneath the sewer, a 9-inch drain consisting of socket pipes, was laid, communicating with a sump from which the subsoil water was continuously pumped during the construction of the works, at the rate occasionally of 600 gallons per minute. The lower half of the sewer is for the most part in clay, above which there are free sand and gravel, charged with water nearly up to the level of the ground. The trench excavated for the sewer nowhere exceeded 14 feet in depth.

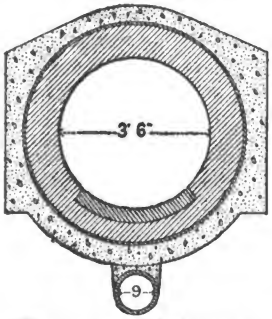

Fig. 105.—3½ Feet Barrel Sewer.

The 18-inch sewer consists of glazed socket pipes, jointed and caulked with tarred hemp, and afterwards filled round with Portland cement mixed in equal parts with fine clean sand. As this portion of the sewer is below water-level, the pipes were surrounded with about 6 inches of concrete, and with clay-puddle where the sewer passes through clay. At its junction with the reservoir, the 18-inch sewer is provided with a flap-valve, for the purpose of preventing sewer-gas from passing inwards to the town.

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At the Lower Ock, a second sump was established in connection with the subsoil drain, exhausted by a second engine. By a junction of this drain with the Lower Ock, the drainage of the low-lying portion of the borough has been considerably improved, as it thus obtains an outlet 5 feet or 6 feet lower than formerly, when it was maintained at the level of the millhead.

The construction of the sewers in the lower part of the town was greatly facilitated by the lowering of the subsoil water.

The manholes, Figs. 106, 107, are circular, tapering upwards. The lower part is generally of concrete, the upper part of brickwork. They are fitted with cast-iron covers and dirt-boxes, with openings for ventilation. Every second or third manhole is provided with a flushing board fitting into a groove, or with a flap-valve.

The flushing inlets consist of 6-inch pipes laid from any conveniently situated manhole to the river, or other source of water supply. Any portion of a sewer above a manhole can be fitted so as to serve as a tank to flush the length below. Manholes capable of holding several hundred gallons serve to flush the smaller sewers.

The work of construction was commenced in May, 1876, and completed in the course of eighteen months, for the sum of £8,750. The work to be done in pumping was fixed at the raising of 400 gallons per minute, 20 feet high. There are two engines, each capable of doing this duty, their aggregate power being equal to half the maximum quantity that the sewers are calculated to deliver in twenty-four hours. They are condensing engines, with double-acting sewage-pumps fixed horizontally in line with the cylinders, all on one bed-plate. The contract price was £826 8s. 9d. The cost of the buildings, with sewage screens, well, weighing machine, fencing, yard, &c., amounted to £1,674; making, for the engines and pumping station together, £2,500. The coal consumed by the engines is about one ton per week. The total annual cost for pumping was, for the first two years, under £150.

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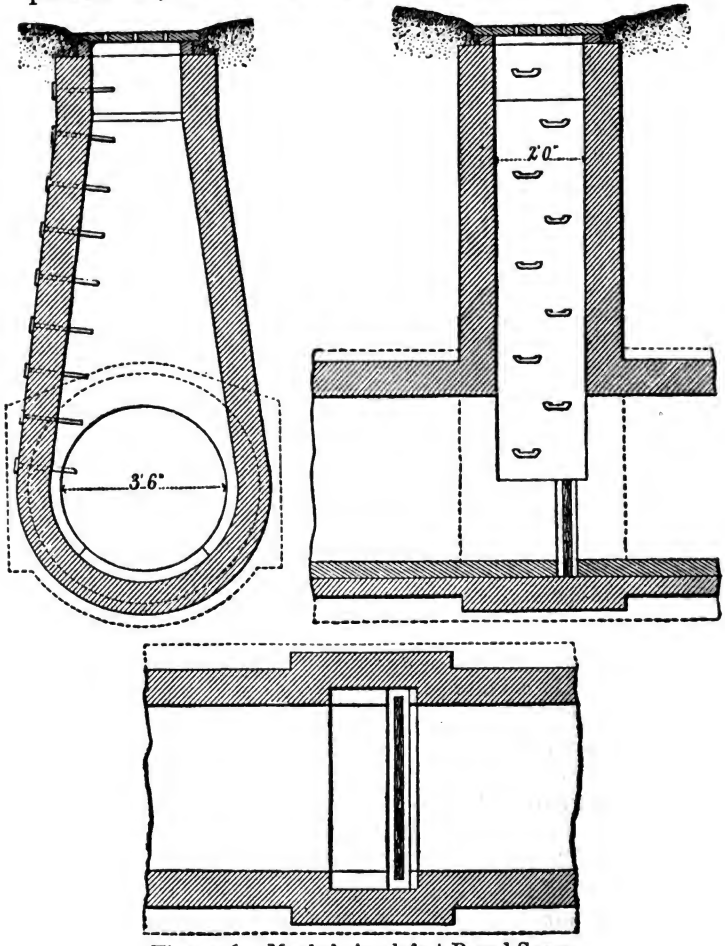
The quantity of land purchased by the Abingdon Corporation is 48 acres, of which 34 acres had been laid out.



Figs. 106.—Manhole in 3½-feet Barrel Sewer.

The cost of the land, including all expenses, was in round numbers, £7,500; the cost of laying out was £2,500;

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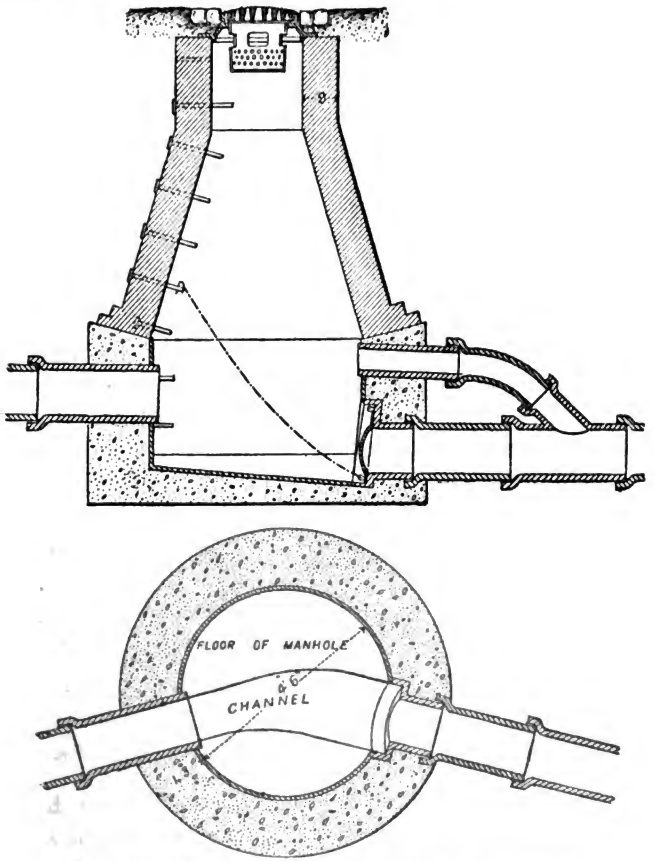
making together £10,000. The total cost of the land, sewage works, engineer's charges, &c., amounted to £23 000.



Figs. 107.—Manhole with 12-inch Flushing Apparatus.

In the autumn of 1857, the sewage was first pumped on the land. From that time, the Thames has been practically free from pollution by Abingdon sewage. That is to

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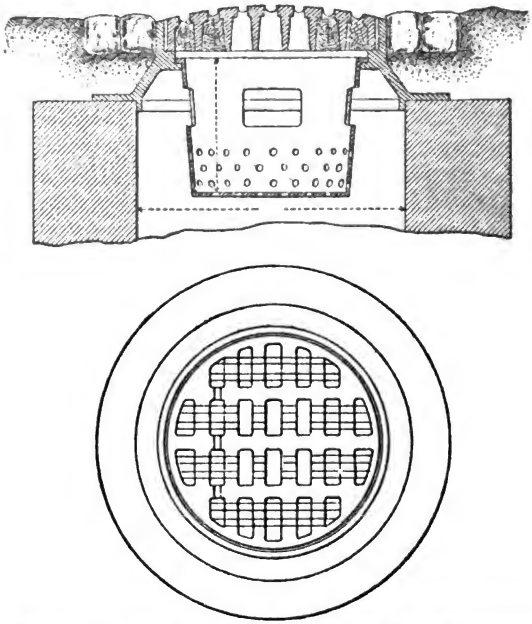
say, the land first receives it, and, after passing through the soil, the effluent water, freed from polluting and contaminating matter, flows into the river. Samples of the effluent water were found, on being analysed, to be less contaminated than the water from some of the wells in use in the town. The farm, with homestead, has been let to a



Figs. 108.—Top of Manhole for Public Roads and Streets.

tenant at £4 10s. per acre per year, the sewage being pumped by the Corporation. The pumping engines are managed by one man. At times one engine, at others both, are kept working for seven or eight hours per day, till the reservoir is empty. But the reservoir can be emptied in the course of five hours by one engine worked at full speed. The reservoir has proved, with few excep-

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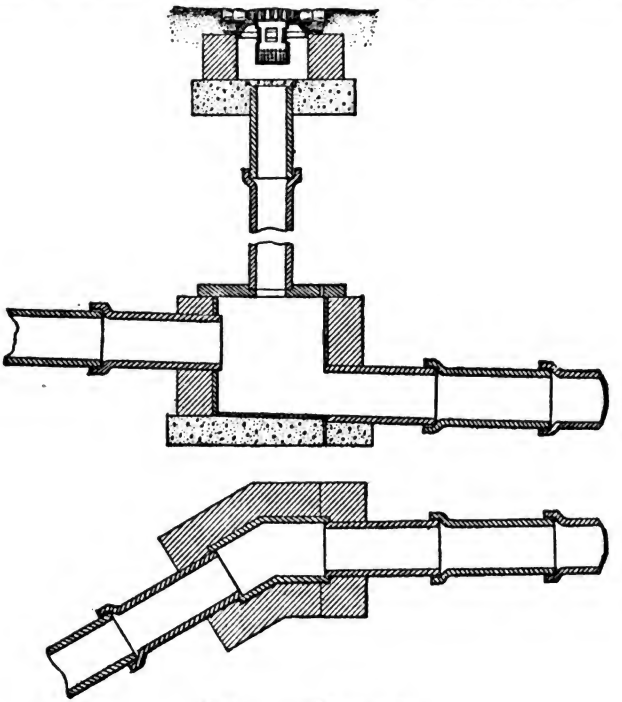
tions, of sufficient capacity to hold all the sewage that collects during the period of cessation from pumping.

The sewers in the town—the 15-inch, 12-inch, and 9-inch pipes—are kept in efficient working order by flushings once or twice a week. The flow of sewage is seldom sufficient to fill the sewers one-half or even one-quarter full,



Figs. 109.—Lamphole.

and the velocity of the current is consequently very moderate, and floating substances become stranded in the sewer. But flushing is the more easily effected, as road detritus is not carried into the sewers.

The sewers are ventilated by numerous shafts—manholes, Figs. 108, or lampholes, Figs. 109—50 or 60 yards

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apart, which maintain a constant interchange of foul sewer air generated within for the fresh air from without.

The area of land laid out for intermittent filtration was 6½ acres, and for wide irrigation 17½ acres. The first is laid out on an almost dead level in ridges and furrows, and is of special use at times when the tenant does not require to use the sewage for his own purposes on other parts of the farm. For wide irrigation, the land is only turned up with the plough after having been roughly levelled; but, in the filtration-areas, the work is done partly with the plough and is finished with the spade. From the pumping station, there are delivery-conduits on to the land, consisting, for the first portion, of 15-inch pipes, and further on of 12-inch pipes. They are laid underground, and are connected together with chambers for the distribution of the sewage. The cost of the preparation of the land for wide irrigation was £70 per acre, and for intermittent filtration £85 per acre.

XI.—Sewage Works at Abergavenny—Sewage Irrigation.

The town of Abergavenny, on the north bank of the river Usk, containing 6,940 inhabitants, was some time since sewered on the combined system, the sewage being treated by filtration through charcoal. The treatment did not give satisfaction, and under the advice of Messrs. Dudley and De Salis, 5 miles of stoneware pipes were laid in 1882, varying in size from 9 inches to 18 inches in diameter, as intercepting sewers. A field also, on the south side of the river, 11 acres in extent, was prepared for the treatment of the sewage by land filtration. The whole of the sewage of the town is conveyed to the filtration-area by gravitation. Manholes and lampholes are placed where required, every manhole being fitted with a flushing valve. The outfall sewer—a 21-inch pipe—is laid below ground to the river Usk, over which it is carried

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by an iron bowstring foot-bridge, erected for the purpose, having a clear span of 130 feet 10 inches. The piping on the bridge is of cast-iron, having turned and bored joints. A plank footpath is constructed above the sewer, and the weight of the bridge and pipes together is 25 tons. From

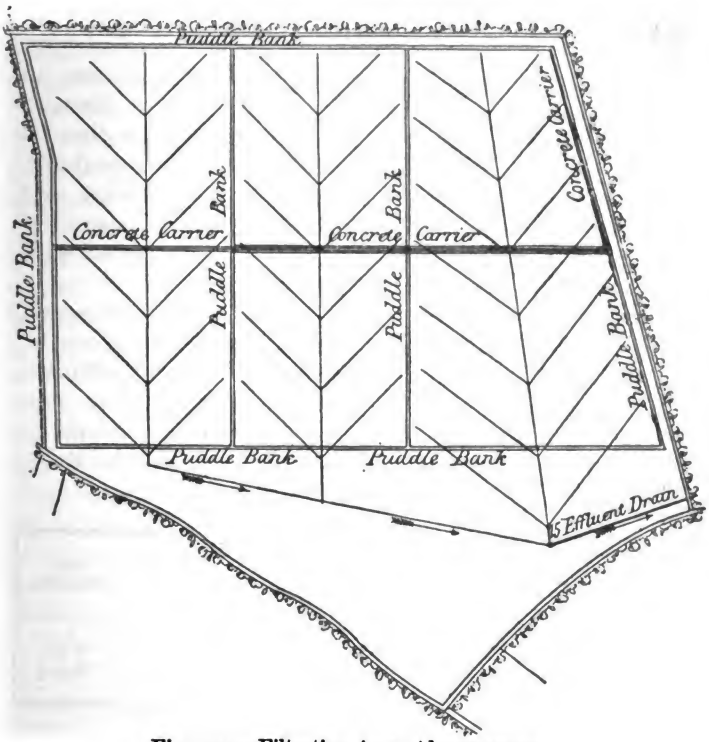

Fig. 110.—Filtration Area, Abergavenny.

the bridge the sewer is carried over the low-lying land on the south side of the river on brick arches and an embankment to the filtration-area. This area, Fig. 110, is enclosed by puddle-banks, and is laid out in six level beds divided by puddle-banks. By means of sluices the

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sewage can be ponded back in concrete carriers, Fig. 111, having level overflow lips, and thus each bed can be evenly flooded. The beds are each about 1¼ acres in area, and each bed contains 10,000 cubic yards of effective filtering material—sandy loam.

Fig. 111.
Concrete Carrier

The dry-weather flow of sewage is 230,000 gallons daily, or 33 gallons per head of the population. A good deal of surface-water, as well as subsoil water, is admitted to the sewers through the old system of sewers; and the wet-weather flow is heavy, amounting, at times, to one million of gallons daily. The sewage is applied to the filter-beds in rotation, and they have to cleanse from 23 to 100 gallons of sewage per cubic yard, once in six days. The beds are cropped with rye grass, which yields a small return.

The system has now been in operation for three years, and the filters, it is stated, have worked satisfactorily, producing at all times a clear and inodorous effluent. During the summer of 1855, four beds only were in constant use; and the following is a comparative analysis by Mr. J. W. Gatehouse, in grains per gallon, of the crude sewage and the effluent water.

—	Solids in Suspension.	Solids in Solution.	Oxygen required to oxidise.	Free ammonia.
Crude sewage	31·60	47·14	2·00	2.43
Effluent water	0·00	30·63	0·514	0·314

The abstraction, here shown, of all solids in suspension proves efficient filtration; and the great diminution in the ammonia and in the oxygen consumed in oxidising the effluent points to a high degree of purification.

The cost of the works was £10,000.

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XII.—The Sewerage of Adelaide, South Australia.—Sewage Irrigation.

Adelaide and its suburbs included in the drainage scheme contained 65,000 inhabitants, in 1882, over an area of 4,000 acres. The drainage has been designed to meet the wants of a rapidly increasing population. The consumption of water varies from 15 gallons per head in winter to 70 gallons in hot weather.

The sewerage of Adelaide was designed and constructed under the supervision of Mr. Oswald Brown. The scheme was framed on the assumption of the general use of water-closets, and the discharge of excreta into the sewer, together with the greater part of the water supplied by the waterworks, after it has been fouled by use; also the rainfall on roofs, paved yards, and courts. The general surface-drainage of the district and of all roads and streets is carried off by a separate system of drains.

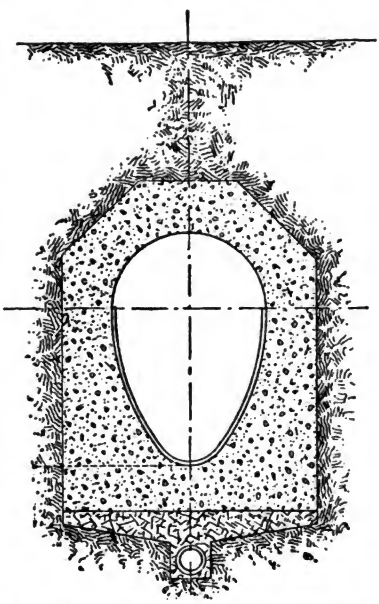

Fig. 112.—Sewers of Cement Concrete.

The larger sewers, Figs. 112, 113, are of the usual oval and other sections, and are constructed entirely of cement-concrete. The smaller sewers are glazed stoneware socket-pipes, mostly imported from England. All joints were made with Portland cement, and, where necessary, the

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pipes were surrounded with cement-concrete or puddled. Ventilating-shafts over the sewers are 100 feet apart, provided, in wide streets, with cast-iron removable gratings, beneath which is an iron basket to catch stones and other matter. In narrow streets, the ventilators are carried up by 6-inch pipes above the housetops. Manholes, of 9-inch brick, are placed over oval sewers 600 feet apart. On pipe-sewers the manholes are entirely of cement-concrete, 4½ feet in diameter at the bottom, tapering upwards, cast in portions round a collapsable iron frame, afterwards withdrawn. These manholes are at all intersections of streets, and at every change of direction, straight lines only being allowed between manholes.

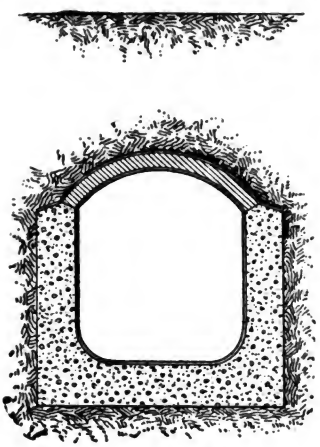

Fig. 113.—Sewer of Cement Concrete.

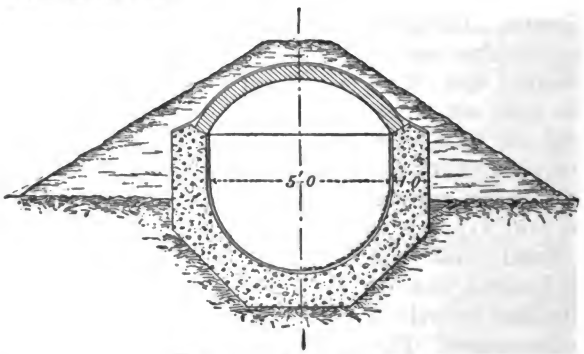

Fig. 114.—Main Outfall.

The whole of the sewage is delivered on a sewage-farm

about three miles from the town. The main outfall, Fig. 114, is peculiar in form. The invert has been kept as high as possible in order that the sewage might be delivered above the surface of the ground, to facilitate the distribution; and the sewer for a considerable distance stands partly above the ground level, covered by a bank of earth. For the disposal of the sewage, an area of 400 acres of land is enclosed, the ground being a light loam overlying a sandy subsoil. Fifty acres have been underdrained to a depth of 6 feet for the purpose of intermittent downward filtration, in order to avoid the necessity, during rain, of flooding the crops grown upon that portion of the farm worked by broad irrigation. The maximum flow of sewage is calculated at 3,700 cubic feet, or 23,000 gallons per minute. A main drain of this capacity below the filter has an outfall to the sea. It is constructed of cement-concrete with a half-brick arch. The minor drains are of perforated stoneware-pipes. The surface of the filter-bed is laid out in ridges and furrows, and is divided into six areas, each of which receives its regular dose of sewage in rotation. According to accounts received after sixteen months' experience of the farm, the results were very encouraging, the produce being disposed of at satisfactory prices. There were fifty cows on the farm, their milk and butter finding a ready sale.

Every house-drain, Fig. 115, is thoroughly self-ventilated. The connections, so far as they are situated beneath the public streets, are constructed by and at the cost of the Hydraulic Engineer's Department of the Ministry of Public Works, which also provides and fixes on each house-drain near the boundary of the premises a "disconnecter-trap." By this trap, the passage of gas from the sewer to the house-drain is prevented; at the same time air is admitted to the drain. At the upper end of every house-drain, and of every branch thereof, a ventilating-pipe is fixed, and is carried up a suitable height—above the adjacent buildings, as in Fig. 115. Soil-pipes, also, are required to be fixed on

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the outside of the house-wall, and carried up of undiminished diameter above the roof for ventilation. It is

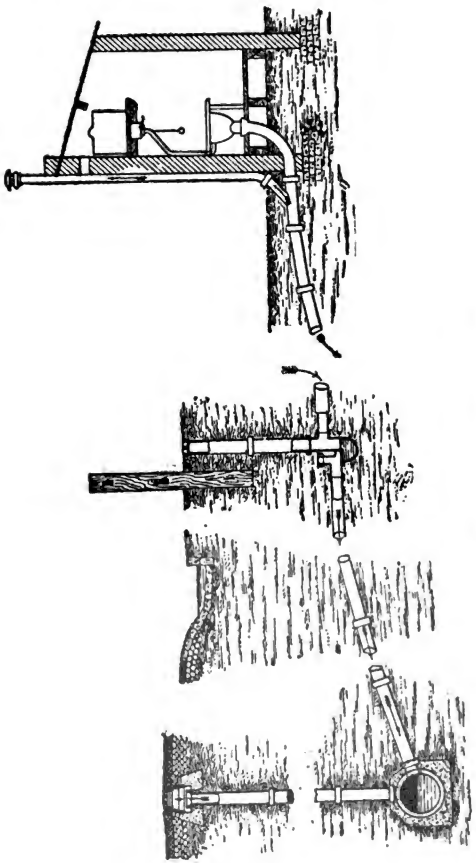

Fig. 115.—House Drainage.

further required that the traps of indoor closets are to be fitted with a 2-inch ventilating-pipe branching into the soil-pipe above the highest inlet into it, where the pipe is free for ventilation. Iron pipes are largely used for house-

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drains, and are much liked for the facility with which they can be laid. They are cast in various lengths up to 9 feet, and are $\frac{3}{16}$ inch thick for 4-inch pipes, and $\frac{1}{4}$ inch for 6-inch pipes, with socket-joints caulked with lead. They are coated with Dr. Angus Smith's composition.

The estimated cost of the whole scheme was £300,000, or £2 per head of the assumed population. The following were the prices of labour and materials:—

Labourers' wages, per day of 8 hours . .	6s. 6d. to 8s.
Masons' ,, ,, ,, . .	10s. 6d. to 12s.
Portland cement, per cask	17s.
Bricks, per thousand	60s.
Broken metal for concrete, per cubic yard .	10s.
Cement concrete, per cubic yard . . .	35s.
Brickwork in cement. per cubic yard . .	60s.

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APPENDIX.

MODEL BYE-LAWS ISSUED BY THE LOCAL GOVERNMENT BOARD FOR THE USE OF SANITARY AUTHORITIES.

EXTRACT FROM SECTION IV. "NEW STREETS AND BUILDINGS."

With respect to the Drainage of Buildings.

60. Every person who shall erect a new building shall cause the subsoil of the site of such building to be effectually drained by means of suitable earthenware field pipes, properly laid to a suitable outfall, whenever the dampness of the site renders such a precaution necessary.

He shall not lay any such pipe in such a manner or in such a position as to communicate directly with any sewer or cesspool, or with any drain constructed or adapted to be used for conveying sewage, but shall provide a suitable trap, with a ventilating opening, at a point in the line of the subsoil drain as near as may be practicable to such trap.

61. Every person who shall erect a new building shall construct the lowest storey of such building at such level as will allow of the construction of a drain sufficient for the effectual drainage of such building, and of the provision of the requisite communication with any sewer into which such drain may lawfully empty, at a point in the upper half diameter of such sewer, or with any other means of drainage with which such drain may lawfully communicate.

62. Every person who shall erect a new building shall, in the construction of every drain of such building, other than a drain constructed in pursuance of the bye-law in that behalf

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for the drainage of the subsoil of the site of such building, use good sound pipes formed of glazed stoneware, or of other equally suitable material.

He shall cause every such drain to be of adequate size, and, if constructed or adapted to be used for conveying sewage, to have an internal diameter not less than *four inches*, and to be laid in a bed of good concrete, with a proper fall, and with water-tight, socketed, or other suitable joints.

He shall not construct any such drain so as to pass under any building, except in any case where any other mode of construction may be impracticable, and in that case he shall cause such drain to be so laid in the ground that there shall be a distance equal at the least to the full diameter thereof between the top of such drain at its highest point and the surface of the ground under such building.

He shall also cause such drain to be laid in a direct line for the whole distance beneath such building, and to be completely embedded in and covered with good and solid concrete, at least *six inches* thick, all round.

He shall likewise cause adequate means of ventilation to be provided in connection with such drain at each end of such portion thereof as is beneath such building.

He shall cause every inlet to any drain, not being an inlet provided in pursuance of the bye-law in that behalf as an opening for the ventilation of such drain, to be properly trapped.

63. Every person who shall erect a new building shall provide, within the curtilage thereof, in every main drain or other drain of such building which may directly communicate with any sewer or other means of drainage into which such drain may lawfully empty, a suitable trap at a point as distant as may be practicable from such building and as near as may be practicable to the point at which such drain may be connected with such sewer or other means of drainage.

64. A person who shall erect a new building shall not construct the several drains of such building in such a manner as to form in such drains any right-angled junction, either vertical or horizontal. He shall cause every branch drain or tributary drain to join another drain obliquely in the direction of the flow of such drain.

65. Every person who shall erect a new building shall, for the purpose of securing efficient ventilation of the drains of such building, comply with the following requirements:—

(i.) He shall provide at least two untrapped openings to the

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drains, and, in the provision of such openings, he shall adopt such of the two arrangements hereinafter specified as the circumstances of the case may render the more suitable and effectual.

(*a.*) One opening, being at or near the level of the surface of the ground adjoining such opening, shall communicate with the drains by means of a suitable pipe, shaft, or disconnecting chamber, and shall be situated as near as may be practicable to the trap which, in pursuance of the bye-law in that behalf, shall be provided between the main drain or other drain of the building, and the sewer or other means of drainage with which such drain may lawfully communicate. Such opening shall also in every case be situated on that side of the trap which is the nearer to the building.

The second opening shall be obtained by carrying up from a point in the drains, as far distant as may be practicable from the point at which the first-mentioned opening shall be situated, a pipe or shaft, vertically, to such a height and in such a manner as effectually to prevent any escape of foul air from such pipe or shaft into any building in the vicinity thereof, and in no case to a less height than *ten feet*.

(*b.*) In every case where the foregoing arrangements of the openings to the drains may be impracticable, there shall be substituted the arrangement hereinafter prescribed.

One opening shall be obtained by carrying up from a point, as near as may be practicable to the trap, which, in pursuance of the bye-law in that behalf, shall be provided between the main drain or other drain of the building and the sewer or other means of drainage with which such drain may lawfully communicate, a pipe or shaft, vertically, to such a height and in such a manner as effectually to prevent any escape of foul air from such pipe or shaft into any building in the vicinity thereof, and in no case to a less height than *ten feet*. Such opening shall also in every case be situated on that side of the trap which is the nearer to the building.

The second opening, being at a point in the drains as far distant as may be practicable from the point at which such last-mentioned pipe or shaft shall be carried up, shall be at or near the level of the surface of the ground adjoining such opening, and shall communicate with the drains by means of a suitable pipe or shaft.

(ii.) He shall cause every opening provided in accordance with either of the arrangements hereinbefore specified to be

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furnished with a suitable grating or other suitable cover for the purpose of preventing any obstruction in or injury to any pipe or drain by the introduction of any substance through any such opening. He shall, in every case, cause such grating or cover to be so constructed and fitted as to secure the free passage of air through such grating or cover by means of a sufficient number of apertures, of which the aggregate extent shall be not less than the sectional area of the pipe or drain to which such grating or cover may be fitted.

(iii.) Every pipe or shaft which may be used in connection with either of the arrangements hereinbefore specified shall be of a sectional area not less than that of the drain with which such pipe or shaft may communicate, and not less in any case than the sectional area of a pipe or shaft of the diameter of *four inches*.

(iv.) No bend or angle shall (except where unavoidable) be formed in any pipe or shaft used in connection with either of the arrangements hereinbefore specified.

(v.) Provided always, that for the purpose of either of the arrangements hereinbefore specified the soil pipe of any watercloset, in every case where the situation, sectional area, height, and mode of construction of such soil pipe shall be in accordance with the requirements applicable to the pipe or shaft to be carried up from the drains, may be deemed to provide the necessary opening for ventilation which would otherwise be obtained by means of such last-mentioned pipe or shaft.

66. A person who shall erect a new building shall not construct any drain of such building in such a manner as to allow any inlet to such drain (except such inlet as may be necessary from the apparatus of any watercloset) to be made within such building.

He shall cause the soil-pipe from every watercloset in such building to be at least *four inches* in diameter, and to be fixed outside such building, and to be continued upwards without diminution of its diameter, and (except where unavoidable) without any bend or angle being formed in such soil pipe to such a height and in such a position as to afford, by means of the open end of such soil pipe, a safe outlet for sewer air.

He shall so construct such soil pipe that there shall not be any trap between such soil pipe and the drains, or any trap (other than such as may necessarily form part of the apparatus of any watercloset) in any part of such soil pipe.

He shall also cause the waste pipe from every bath, sink

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(not being a slop sink constructed or adapted to be used for receiving any solid or liquid filth), or lavatory, the overflow pipe from any cistern and from every safe under any bath or watercloset, and every pipe in such building for carrying off waste water, to be taken through an external wall of such building, and to discharge in the open air over a channel leading to a trapped gully grating at least *eighteen inches* distant.

He shall, as regards the mode of construction of the waste pipe from any slop sink constructed or adapted to be used for receiving within such building any solid or liquid filth, comply in all respects with such of the provisions of this bye-law as are applicable to the soil pipe from a watercloset.

With respect to Waterclosets.

67. Every person who shall construct a watercloset or earthcloset in a building shall construct such watercloset or earthcloset in such a position that one of its sides at the least shall be an external wall.

68. Every person who shall construct a watercloset or earthcloset in connection with a building, whether the situation of such watercloset or earthcloset be or be not within such building, shall construct in one of the walls of such watercloset or earthcloset a window of not less dimensions than *two feet* by *one foot*, exclusive of the frame, and opening directly into the external air.

He shall, in addition to such window, cause such watercloset or earthcloset to be provided with adequate means of constant ventilation by at least one air-brick built in an external wall of such watercloset or earthcloset, or by an air shaft, or by some other effectual method or appliance.

69. Every person who shall construct a watercloset in connection with a building shall furnish such watercloset with a separate cistern, service box, or flushing box of adequate capacity, which shall be so constructed, fitted, and placed as to admit of the supply of water for use in such watercloset without any direct connection between any service pipe upon the premises and any part of the apparatus of such watercloset, other than such cistern, service box, or flushing box.

He shall furnish such watercloset with a suitable apparatus for the effectual application of water to any pan, basin, or other receptacle with which such apparatus may be connected and

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used, and for the effectual flushing and cleansing of such pan, basin, or other receptacle, and for the prompt and effectual removal therefrom of any solid or liquid filth which may from time to time be deposited therein.

He shall furnish such watercloset with a pan, basin, or other suitable receptacle of non-absorbent material, and of such shape, of such capacity, and of such mode of construction as to receive and contain a sufficient quantity of water, and to allow all filth which may from time to time be deposited in such pan, basin, or receptacle to fall free of the sides thereof, and directly into the water received and contained in such pan, basin, or receptacle.

He shall not construct or fix under such pan, basin, or receptacle any "container" or other similar fitting.

He shall not construct or fix in or in connection with the watercloset apparatus any trap of the kind known as a "D trap."

As to the giving of Notices, Deposit of Plans, &c.

92. Every person who shall intend to erect a building shall give to the Sanitary Authority notice in writing of such intention, which shall be delivered or sent to their clerk at his or their office, or to their surveyor at his or their office, and shall at the same time deliver or send, or cause to be delivered or sent to their clerk at his or their office, or to their surveyor at his or their office, complete plans and sections of every floor of such intended building, which shall be drawn to a scale of not less than *one inch* to every *eight feet*, and shall show the position, form, and dimensions of the several parts of such building, and of every watercloset, earthcloset, privy, ashpit, cesspool, well, and all other appurtenances.

Such person shall at the same time deliver or send, or cause to be delivered or sent to the clerk to the Sanitary Authority at his or their office, or to their surveyor at his or their office, a description in writing of the materials of which it is intended that such building shall be constructed, and of the intended mode of drainage and means of water supply,

Such person shall at the same time deliver or send, or cause to be delivered or sent to the clerk to the Sanitary Authority at his or their office, or to their surveyor at his or their office, a block plan of such building, which shall be drawn to a scale of not less than *one inch* to every *forty-four feet*, and shall show the position of the buildings and appurtenances of the properties

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immediately adjoining, the width and level of the street in front, and of the street, if any, at the rear of such building, the level of the lowest floor of such building, and of any yard or ground belonging thereto.

Such person shall likewise show on such plan the intended lines of drainage of such building, and the intended size, depth, and inclination of each drain; and the details of the arrangement proposed to be adopted for the ventilation of the drains.

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